National Aeronautics and Space Administration

HAT DRMs 2013

September 30, 2013

Background

NASA uses a set of Design Reference Missions (DRMs) to help focus capability development activities across the agency

The DRMs are intended to show capability needs and represent a set of various implementations

The “mission class” context is used to establish temporal priorities and a LIMITED set of DRMs is used to capture driving mission capabilities

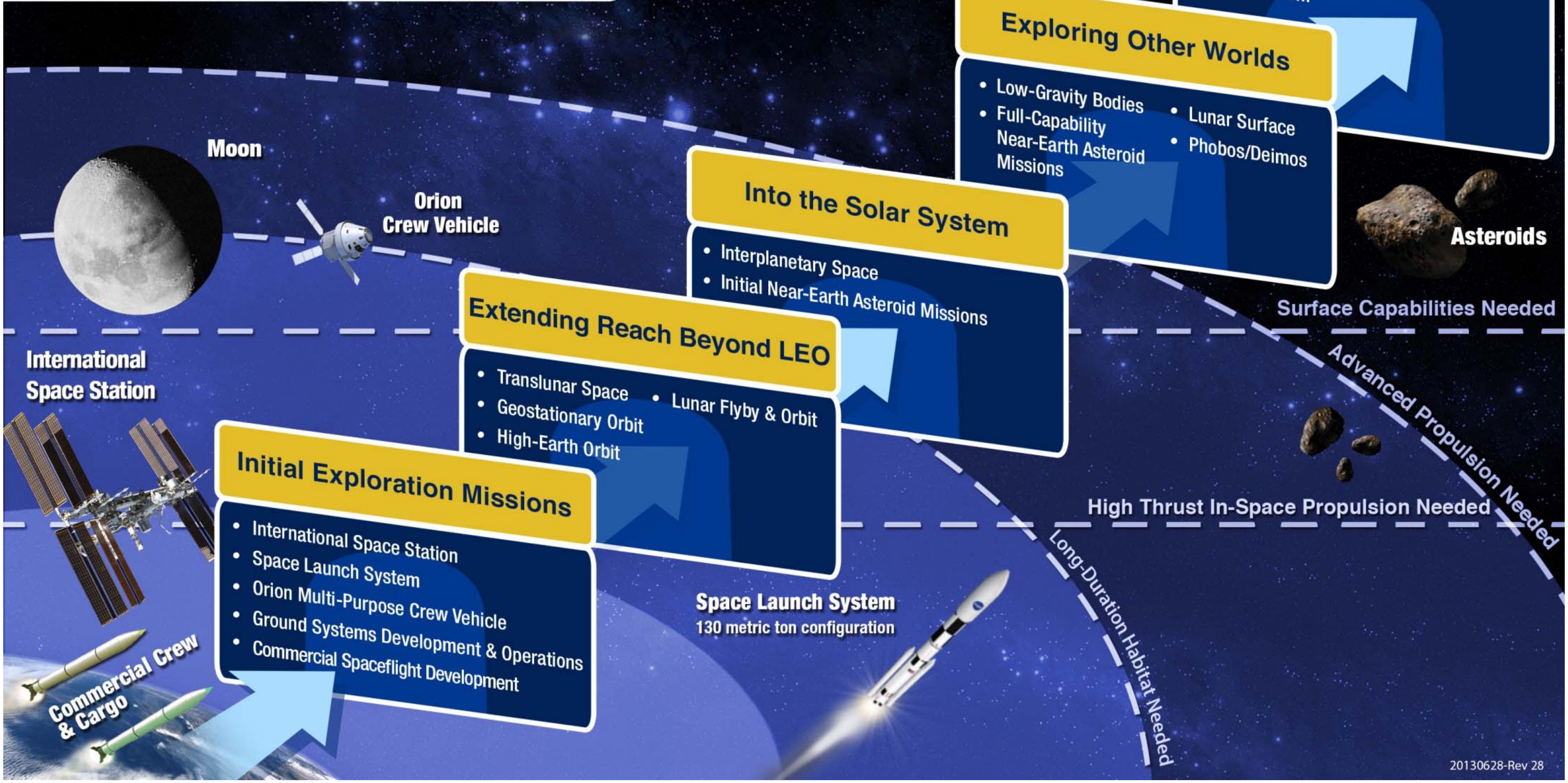
The DRMs represent a snapshot in time of current thinking, and do not represent all potential future missions

The DRMs are generic in nature, with stated assumptions for some supporting capabilities and elements - they do not represent firm requirements

SLS/Orion DRMs are being developed and refined as part of the development program for SLS & Orion and are not included in this package.

Capability Driven Framework

Incremental steps to steadily build, test, refine, and qualify capabilities that lead to affordable flight elements and a deep space capability.



Human Exploration Design Reference Missions

Initial Exploration Missions	Extending Reach Beyond LEO	Into The Solar System	Exploring Other Worlds	Planetary Exploration

ISS Utilization →

★ SLS/Orion (EM-1:Exploration Mission 1, Uncrewed Lunar Flyby Mission)

★ SLS/Orion (EM-2: Exploration Mission 2, Lunar Orbit Crewed Mission)

★ SLS/Orion (EM-X: Exploration Mission X, Crewed Mission)

★ Translunar missions

★ Crewed Visit to a Redirected Asteroid

★ Crew to NEA Mission

★ Crew to Lunar Surface (ISECG GER)

★ Crew to Lunar Surface (Minimal)

★ Mars Test on Moon

★ Crewed Mars Moons Mission

Crewed Mars Orbital Mission ★

Crewed Mars Surface Mission (DRA 5.0) ★

Crewed Mars Surface Mission (Minimal) ★

Gold – Mission under development
White – Primary Design Reference Mission
Green – Secondary Design Reference Mission
Blue – Internationally Led Design Reference Mission

Notes:

Design Reference Missions serve to define bounding cases of capabilities required to conduct missions.

They are intended to serve as a framework for understanding the capabilities and technologies that may be needed, but are not specific actual missions to be conducted.

Design Reference Missions updated periodically

Evolution of Key Assumptions that Drive Transportation System Performance

2011 HEFT	2012 Cycle-A	2012 Cycle-B	2012 Cycle-C+	2013 Cycle-A
10% Architecture Reserve • on wet cargo stack (+ adapter) mass	**5% Level I Customer Reserve** • on wet cargo stack (+ adapter) mass	**5% Level I Customer Reserve** • on wet cargo stack (+ adapter) mass	**5% Level I Customer Reserve** • on wet cargo stack (+ adapter) mass	**5% Level I Customer Reserve** • on wet cargo stack (+ adapter) mass
2.5% launch vehicle adapter mass • on wet cargo stack mass	**2.5% launch vehicle adapter mass** • on wet cargo stack mass	**2.5% launch vehicle adapter mass** • on wet cargo stack mass	**2.5% launch vehicle adapter mass** • on wet cargo stack mass	**5% launch vehicle adapter mass** • on wet cargo stack mass
1% Flight Performance Reserve on ΔVs	**5% Flight Performance Reserve on ΔVs**	**5% Flight Performance Reserve on ΔVs**	**5% Flight Performance Reserve on ΔVs** • Except for Orion burns	**1% Flight Performance Reserve on Main ΔVs** • Except for Orion burns • 5% on RCS ΔV's • 0% on Terminal Descent/Landing • 0% on Mars Ascent
Elements Margins • Orion: data provided • Other elements: 30% MGA	**Elements Margins** • Orion: data provided • CPS BLK1: 15% • Other elements: 30% MGA	**Elements Margins (Derived from AIAA Standards)** • Orion: data provided • Other elements: 30% MGA	**Elements Margins (Derived from AIAA Standards)** • Orion : data provided • CPS BLK1 - 18.8%, • CPS BLK2 - 21.2% • Lander: Margin remains on lunar surface • Other elements: 30% MGA	**Elements Margins (Derived from AIAA Standards)** • Unknown
Insertion orbit: • 55.56 x 240.76 km	**Insertion orbit:** • 55.56 x 240.76 km	**Insertion orbit:** • -87 km X 241 km	**Insertion orbit:** • -87 km X 241 km	**Insertion orbit:** • -93 km X 370 km
Crew of 3 on Lunar & NEA missions	**Crew of 3 on Lunar & NEA missions**	**Crew of 4 on Lunar & NEA missions**	**Crew of 2~4 on Lunar & NEA missions**	**DRM-9: 6 crew** **DRM-9a: 4 crew**
25 meter SLS shroud barrel	**25 meter SLS shroud barrel**	**18 meter SLS shroud barrel**	**18 meter SLS shroud barrel**	**25 meter SLS shroud barrel**

Primary Design Reference Missions

DRM Title	Destination	Mission Class
Mission Under Development		
EM-1:Exploration Mission 1 *(not currently in package)*	Translunar	Extending Reach Beyond LEO
EM-2: Exploration Mission 2 *(not currently in package)*	Translunar	Extending Reach Beyond LEO
EM-X: Exploration Mission X *(not currently in package)*	Translunar	Extending Reach Beyond LEO
Primary DRMS		
DRM - 5: Crewed Visit to a Redirected Asteroid	Lunar DRO	Into the Solar System
DRM - 8: Crewed Mars Moons Mission	Mars Moons	Exploring Other Worlds
DRM - 8a: Crewed Mars Orbital Mission	Mars Orbit	Planetary Exploration
DRM - 9: Crewed Mars Surface Mission (DRA 5.0)	Mars Surface	Planetary Exploration
DRM - 9a: Crewed Mars Surface Mission (Minimal)	Mars Surface	Planetary Exploration
NASA Support of Internationally Led Design Reference Mission		
DRM - 7: Crew to Lunar Surface (ISECG GER)	Moon	Exploring Other Worlds
Secondary DRMs		
Translunar Missions *(not currently in package)*	Translunar	Extending Reach Beyond LEO
DRM - 6: 3-Launch SLS-Class Crewed NEA Mission *(not currently in package)*	NEA	Exploring Other Worlds
DRM - 7a: Crew to Lunar Surface (Minimal) *(not currently in package)*	Moon	Exploring Other Worlds
DRM - 7b: Mars Test on Moon *(not currently in package)*	Moon	Exploring Other Worlds

Crewed Visit to a Redirected Asteroid

Crewed Visit to a Redirected Asteroid

Achievements

- Demonstration of core capabilities for deep space missions
- Demonstration of ability to work and interact with a small zero g planetary body
- Enable initial understanding of planetary defense challenges and asteroid resource utilization potential
- Establishment of a platform for possible exploration test beds, science missions, international and commercial partnership opportunities

Mission Operations

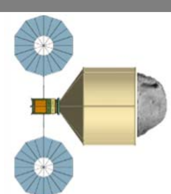
- Total mission duration of 24-30 days and 2 crew members
- Crew and Orion rendezvous with ARV in lunar DRO
- Lunar gravity assists used on both outbound and return
- Asteroid stay time ~6 days, no option to abort during this period
- Two EVAs to recover samples and limited exploration of asteroid

Assumed Element Capabilities


Block 1 SLS

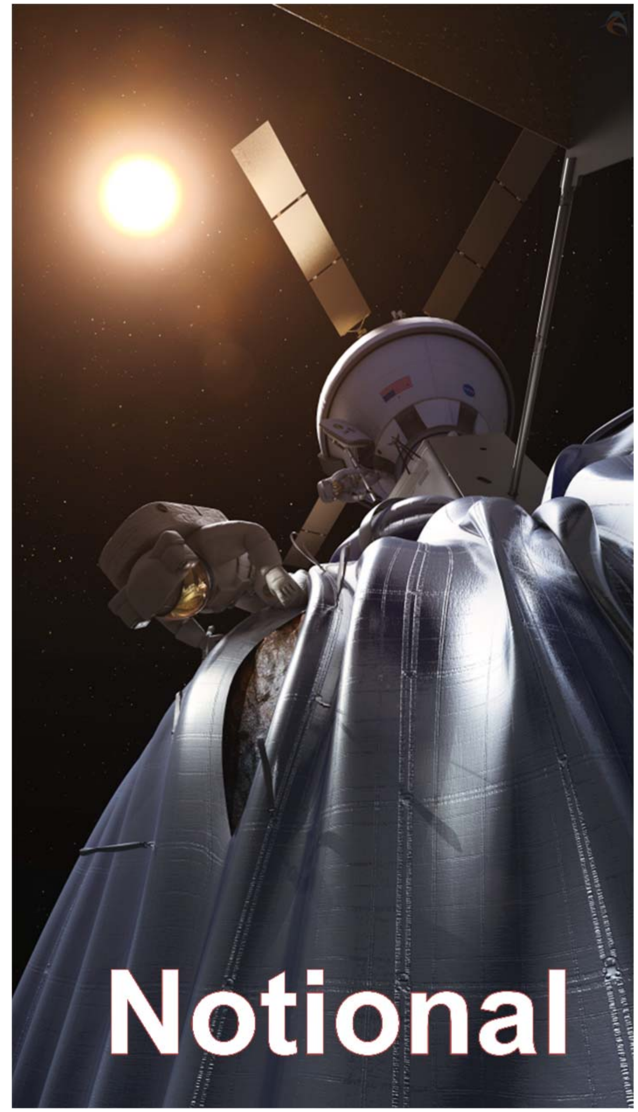

ICPS


Orion “Block 0 BEO”


ARV

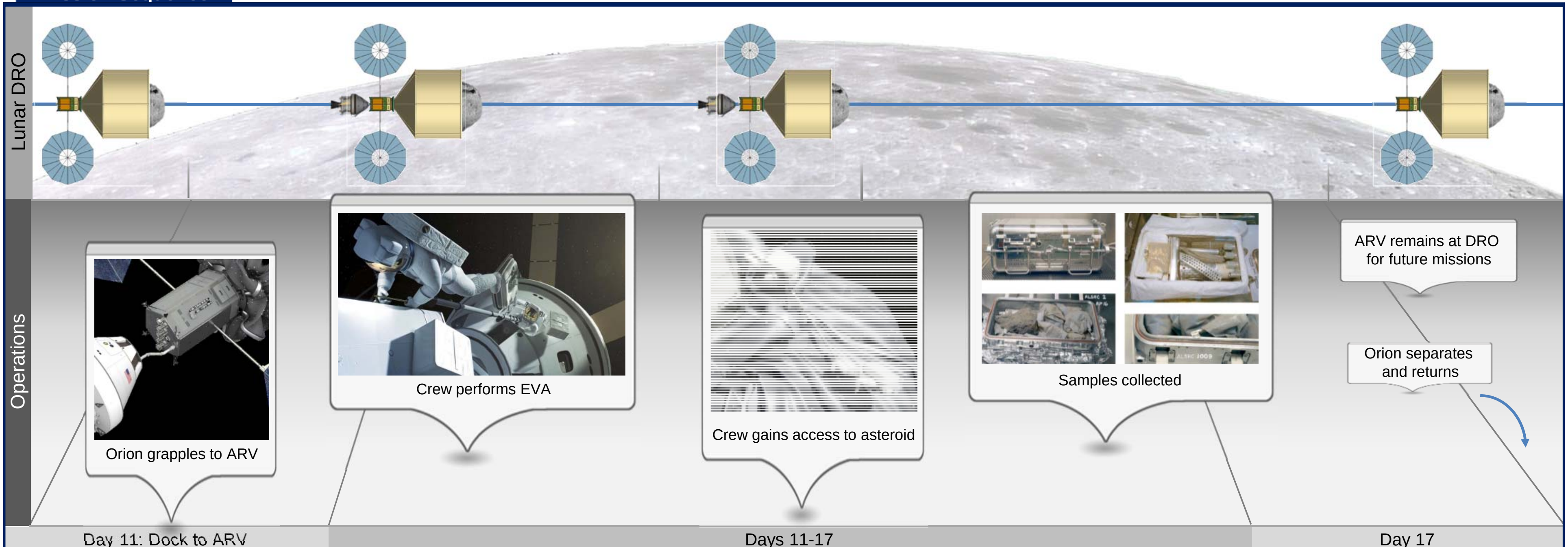
Cross-Cutting Capabilities (Mission Kits)

- EVA Mission Kit
- Orion Grapple Arm / Docking System
- Relative Navigation



Crewed Visit to a Redirected Asteroid Notional Destination Operations

Mission Sequence

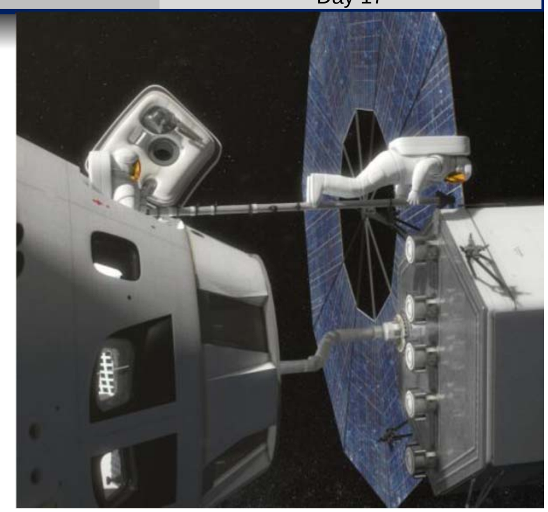


Mission Summary

Two crew members visit a redirected asteroid that is located at a lunar distant retrograde orbit (DRO). The crew will translate via EVA to sites of interest on the asteroid, take measurements and extract samples to be returned back to Earth.

Mission Benefits

- Reduces risk for future human and robotic exploration missions
- Enhances space science, asteroid resource potential, and planetary defense
- Demonstrates capabilities required for future exploration missions
- Demonstrates ability to work and interact with a small planetary body



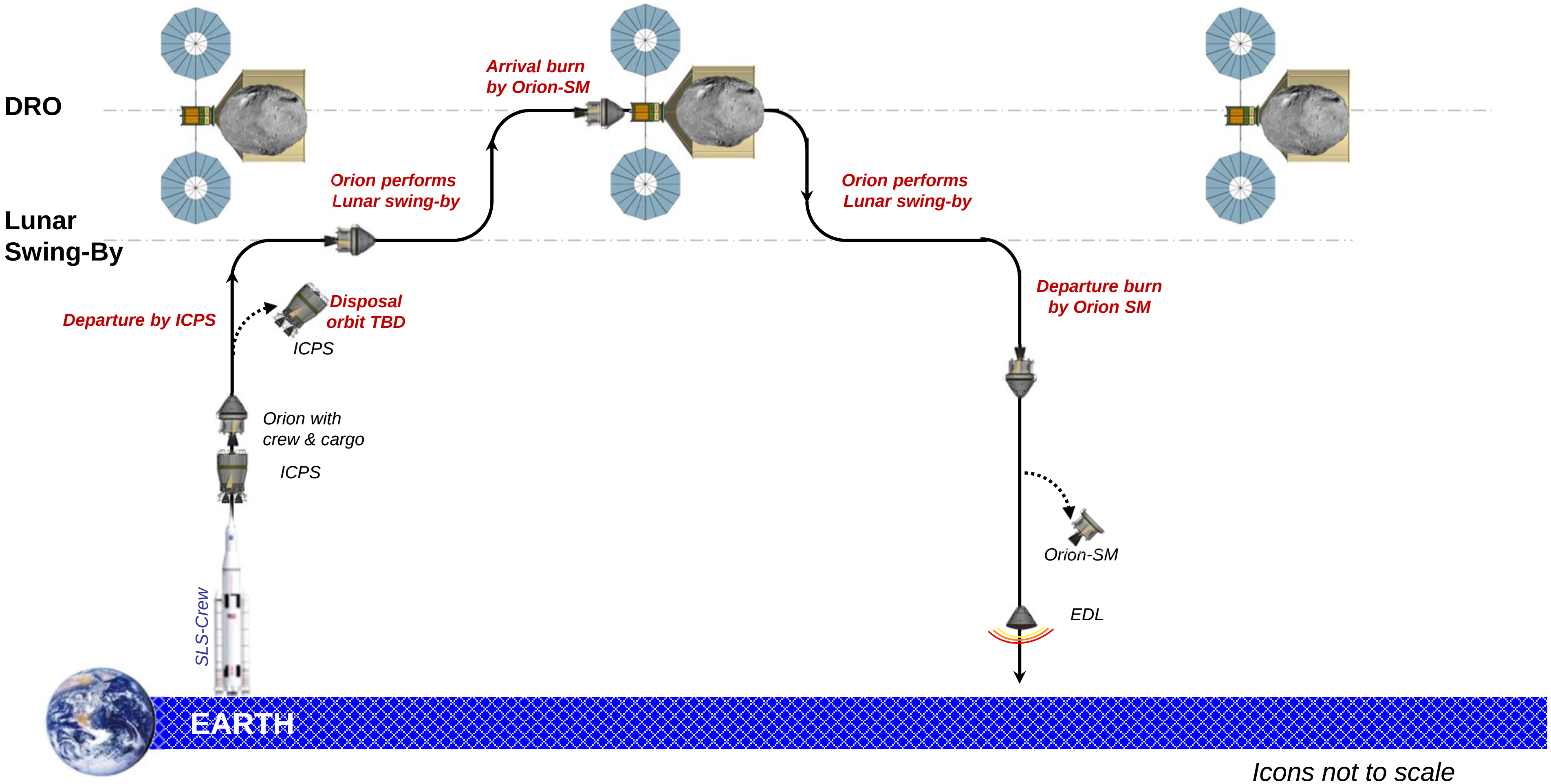
Crewed Visit to a Redirected Asteroid Notional Destination Operations

- After docking, final EVA and cabin preparations
- Orion RCS thrusters are used to slew the stack to a +15° yaw
- EVA 1 Prep
  - Suit donning; perform suit pressure integrity and system checks; pre-breathe period; and cabin depressurization and opening of hatch
- EVA 1
  - Sample retrieval, contextual and detailed photographic observations, EVA tool and translation aid deployment
- Orion RCS thrusters are used to return the stack to its nominal solar inertial attitude
- Suit refurbishment
- EVA 2 Prep
  - Suit donning; perform suit pressure integrity and system checks; pre-breathe period; and cabin depressurization and opening of hatch
- EVA 2
  - Sample retrieval, contextual and detailed photographic observations
- Orion RCS thrusters are used to return the stack to its nominal solar inertial attitude
- Contingency margin, Housekeeping, Departure Prep

Crewed Visit to a Redirected Asteroid Transportation Concept of Operations

Transportation:
- Block 1 SLS
- ICPS
- Crewed Mission Duration: 24-30 d
- 2 Crew members

Destination:
- Time at Destination: ~6 d
- Samples/Cargo returned to Earth: ~10 kg
  - Type: n/a



Icons not to scale

Crewed Visit to a Redirected Asteroid Capabilities Required Beyond State of the Art (1 of 1)

Element	High-level Capability Assumptions	Capability Areas	Potential HAT TechDev Technologies
Block 1 SLS	Block 1 SLS to LEO	BEO Access	• Advanced, low Cost Engine Technology for HLLV
ICPS	Possible in-space restart, I_{sp} = 466 s	BEO Access	
SM	Long-duration propellant storage, Multiple restarts, I_{sp} = 316 s (NTO/MMH), provide power generation and energy storage for Orion	BEO Access; In-Space Propulsion; Power	
Orion	Support 2 crew for ~22-day transit to/from ARV; Rendezvous and grapple (or dock with) ARV; Provide communications between EVA suits, ARV, and Earth; Support approximately 2-3 two-crewmember EVAs; Provide Earth entry capability from lunar speeds (~11 km/s); Provide EVA mobility aids (EVA boom)	BEO Access; Habitation; ECLSS; EVA; Radiation; Avionics; Communication & Navigation.; Thermal; Structures, Materials & Mechanisms	• Common Avionics • High Rate, Adaptive, Internetworked Proximity Communications • Robust Ablative Heat Shield – Thermal Protection System • Space Radiation Protection and Shielding – SPE • Deep Space Suit
Robotic Spacecraft	Autonomously rendezvous and dock with asteroid; Provide mechanism to capture asteroid; 40 kW SEP; Provide solar arrays to produce ~50 kW; Provide communications with Earth, Orion, and EVA suits	In-Space Propulsion; Structures, Materials & Mechanisms; Robotics; Power and Energy Storage; Avionics; Comm. & Nav.	• AR&D and Proximity Operations • Common Avionics • Deep Space Suit • High Rate, Adaptive, Internetworked Prox. Comm. • Suit Port

Note: Capability needs still under assessment

Crewed Mars Moons Mission

Crewed Mars Moons Mission

Achievements

- Crewed mission to the Martian system
- Deep-space use of advanced propulsion (NTP, NEP, and/or SEP)
- Multi-year flight of DSH
- Farthest distance that humans have traveled from Earth

Mission Operations

- Launch, Earth-orbit rendezvous and delivery to Martian system of pre-deployed cargo & propulsive elements
- Launch and Earth-orbit rendezvous of crewed systems & propulsive elements
- Launch of crew and rendezvous with stack and delivery to Martian System
- Total mission duration with direct entry at Earth: ~600 day (opposition-class/short-stay) to ~1000 day (conjunction-class/long-stay)

Assumed Element Capabilities

TBD t Class SLS | CPS | Orion “Block N” | LSS | Long Duration DSH | Advanced EVA Systems | Teleoperated Robots | Advanced Propulsion (NTP shown) | Mars Orbital Excursion Vehicle (MOEV) (SEV + Transfer Stage)

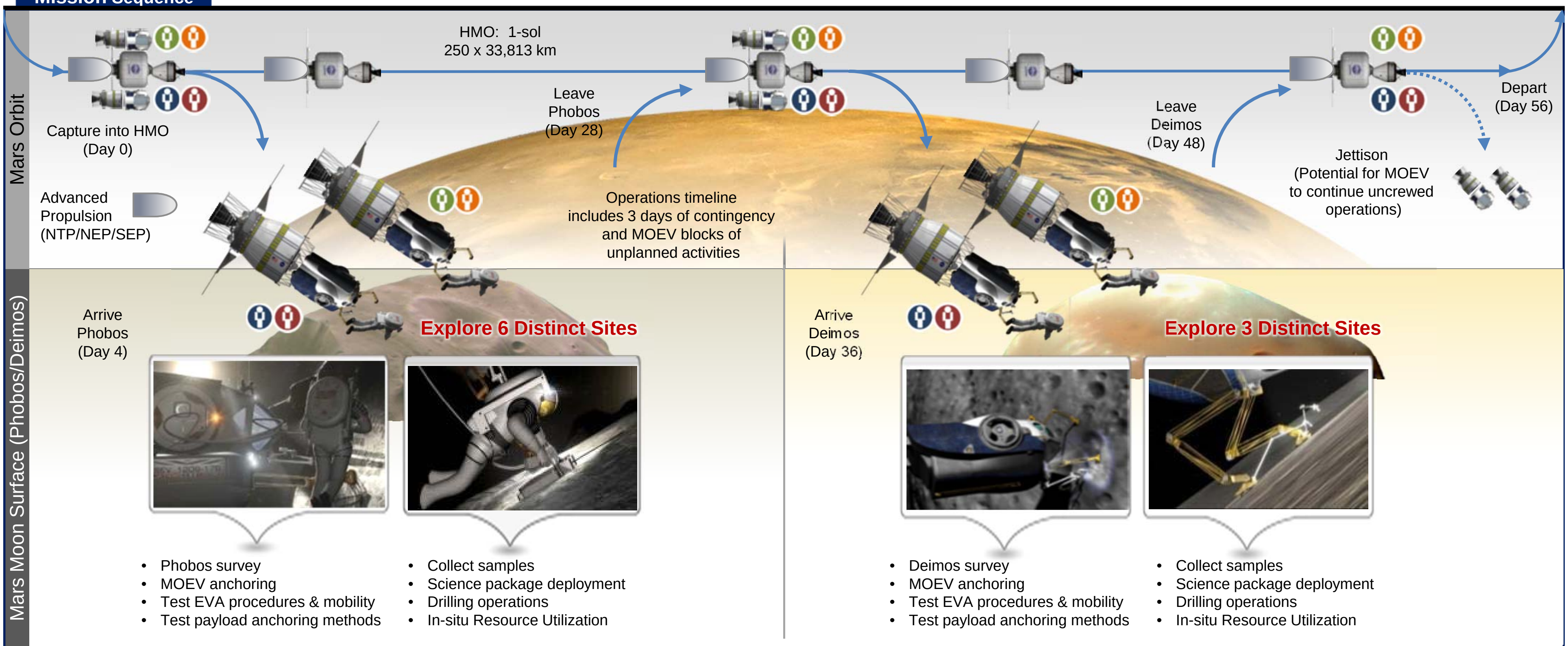
Cross-Cutting Capabilities

- Advanced propulsion (NTP, NEP, and/or SEP) & trade aerocapture and In-Situ Propellant Production
- Long-duration spaceflight healthcare and countermeasures
- Autonomous vehicle systems management
- AR&D
- Low-gravity body anchoring systems, proximity ops, & target relative navigation
- Mechanisms for long-duration, deep-space missions

Crewed Mars Moons Mission Notional Destination Operations

Short-Stay Mars Vicinity Operations

Mission Sequence



Mission Summary

Assumed Mars Orbit Strategy

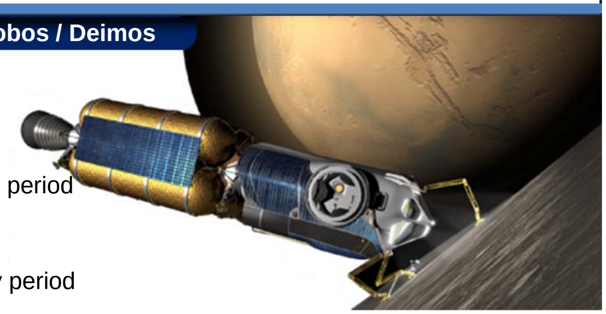
1. Capture into 1-sol parking orbit with proper plane change to match departure asymptote
2. Leave MTV in parking orbit
3. Prepare for orbital operations
4. Utilize MOEVs to explore Phobos for 24 (TBR) days (~1,370 - 3,170 m/s ΔV required)
5. Utilize MOEVs to explore Deimos for 12 (TBR) days (~1,700 - 2,770 m/s ΔV required)
6. Prepare for Mars departure
7. Trans-Earth injection

Mission Site: Phobos / Deimos

Crew: 4

Deimos:
23,459 km ~circular
0.9 deg incl.; 1.26 day period

Phobos:
9,378 km ~circular
1.1 deg incl.; 0.32 day period



Crewed Mars Moons Mission Notional Destination Operations

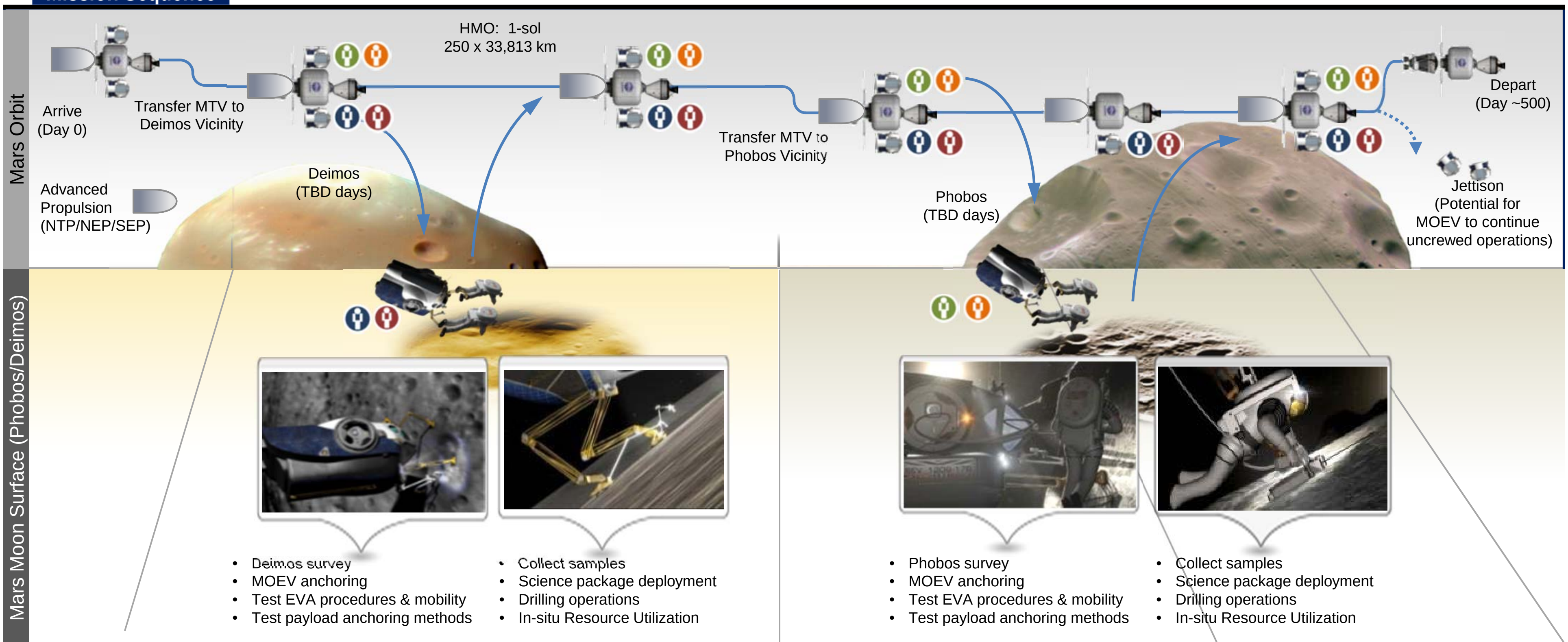
Short-Stay Mars Vicinity Operations

- The stack (DSH and Orion) captures into High-Mars Orbit
  - Potential docking to pre-deployed cargo
- 2 crew transfer from stack to MOEV-1 and 2 crew transfer from stack to MOEV-2
- MOEVs with transfer stages depart from stack and perform orbital maneuvers to rendezvous with Phobos
- MOEVs use robotic arms to anchor to the Phobos surface and provides astronaut platforms during EVA
- Perform Phobos exploration (6 sites)
  - Phobos survey
  - MOEV anchoring, test EVA procedures, mobility, and payload anchoring methods
  - Collect samples, science package deployment, drilling operations, and In-Situ Resource Utilization
- MOEVs with transfer stages return to stack and crew transfer back to DSH
- 2 crew transfer from stack to MOEV-1 and 2 crew transfer from stack to MOEV-2
- MOEVs with transfer stages depart from stack and perform orbital maneuvers to rendezvous with Deimos
- MOEVs use robotic arms to anchor to the Phobos surface and provides astronaut platforms during EVA
- Perform Deimos exploration (3 sites)
  - Deimos survey
  - MOEV anchoring, test EVA procedures, mobility, and payload anchoring methods
  - Collect samples, science package deployment, drilling operations, and In-Situ Resource Utilization
- MOEVs with transfer stages return to stack and crew transfer back to DSH
- MOEVs and transfer stages are jettisoned with the potential to perform uncrewed exploration and science activities
- The stack (DSH and Orion) departs Mars orbit with crew for return to Earth

Crewed Mars Moons Mission Notional Destination Operations

Long-Stay Mars Vicinity Operations

Mission Sequence



Mission Summary

Assumed Mars Orbit Strategy

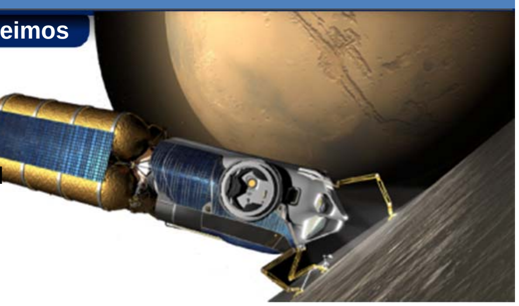
1. Capture into 1-sol parking orbit with proper plane change to Deimos inclination
2. Lower Mars Transfer Vehicle to Deimos orbit
3. Prepare for orbital operations
4. Utilize MOEV(s) to explore Deimos numerous times
5. Lower Mars Transfer Vehicle to Phobos orbit
6. Utilize MOEV(s) to explore Phobos numerous times
7. Raise to parking orbit (planar)
8. Trans-Earth Injection including plane change

Mission Site: Phobos / Deimos

Crew: 4

Deimos:
20,063 km circular
0.9 deg, 1.26 day period

Phobos:
5981 km circular
1 deg, 0.32 day period



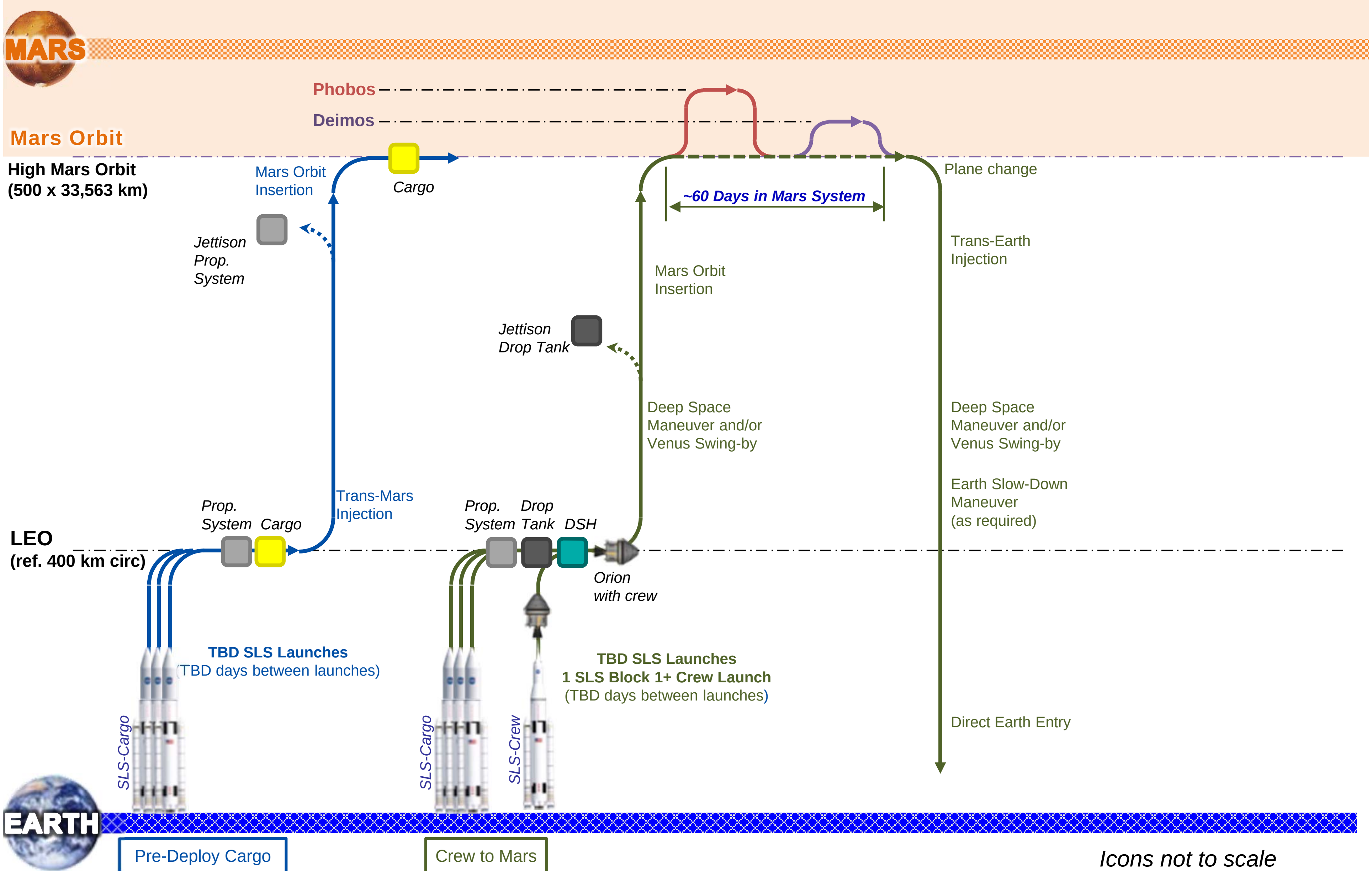
Crewed Mars Moons Mission Notional Destination Operations

Long-Stay Mars Vicinity Operations

- The stack (DSH and Orion) captures into High-Mars Orbit
  - Potential docking to pre-deployed cargo
- Stack performs orbital maneuvers to rendezvous with Deimos
- 2 crew transfer from stack to MOEV-1
- MOEV-1 uses robotic arms to anchor to the Deimos surface and provides astronaut platforms during EVA
- Perform Deimos exploration (TBD sites)
  - Deimos survey
  - MOEV anchoring, test EVA procedures, mobility, and payload anchoring methods
  - Collect samples, science package deployment, drilling operations, and In-Situ Resource Utilization
- MOEV-1 returns to stack and crew transfer back to DSH
- MOEV-based exploration of Deimos is repeated with alternating MOEVs and 2-person crews for TBD period of time
- Stack performs orbital maneuvers to rendezvous with Phobos
- 2 crew transfer from stack to MOEV-1
- MOEV-1 uses robotic arms to anchor to the Phobos surface and provides astronaut platforms during EVA
- Perform Phobos exploration (TBD sites)
  - Phobos survey
  - MOEV anchoring, test EVA procedures, mobility, and payload anchoring methods
  - Collect samples, science package deployment, drilling operations, and In-Situ Resource Utilization
- MOEV-1 returns to stack and crew transfer back to DSH
- MOEV-based exploration of Phobos is repeated with alternating MOEVs and 2-person crews for TBD period of time
- MOEVs are jettisoned with the potential to perform uncrewed exploration and science activities
- The stack (DSH and Orion) departs Mars orbit with crew for return to Earth

Crewed Mars Moons Mission Architecture – Short-Stay

High-Thrust Missions



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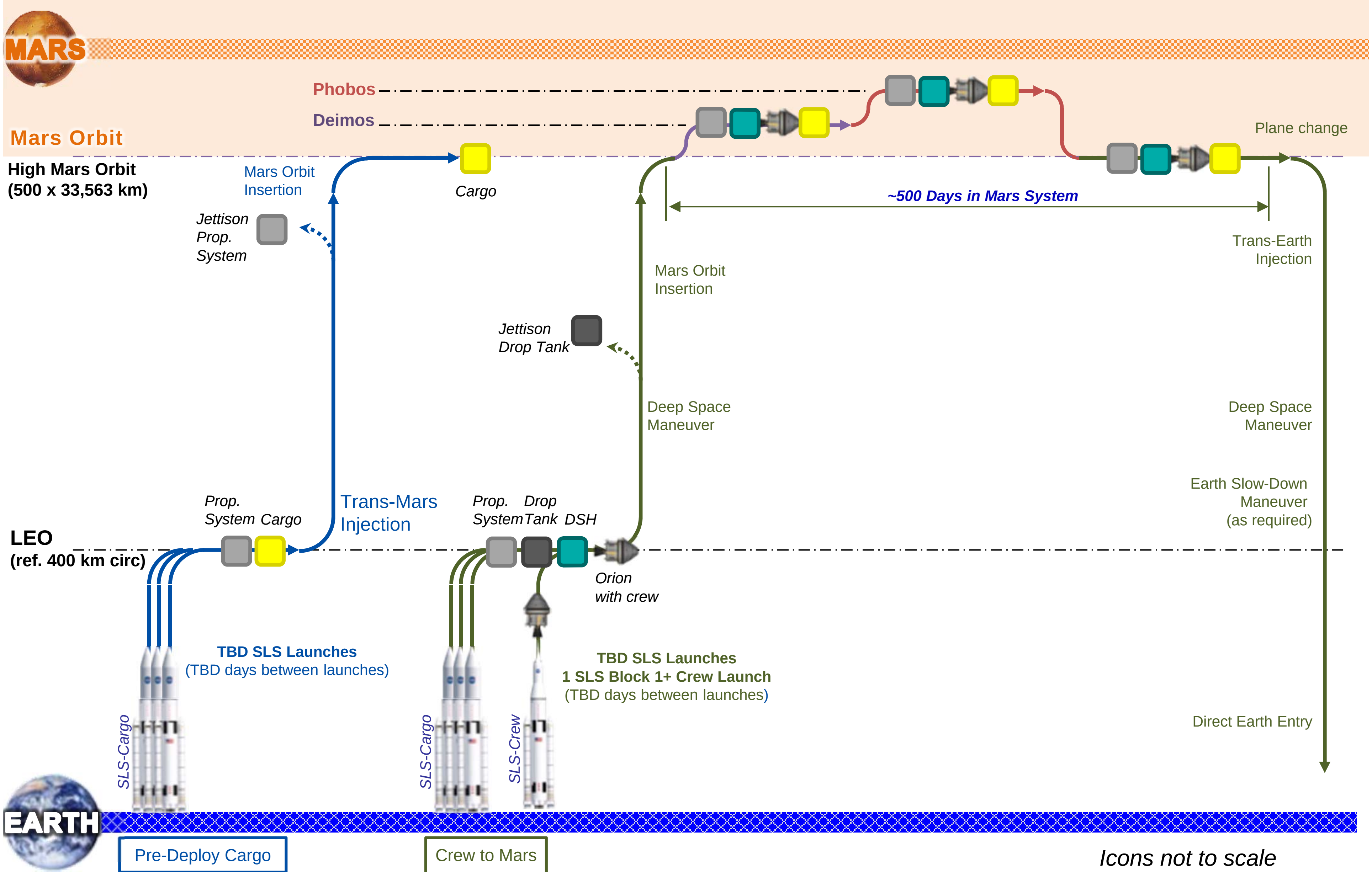
Crewed Mars Moons Mission Architecture – Long-Stay

High-Thrust Missions



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Crewed Mars Moons Mission Potential Capabilities (1 of 2)

Element	High-level Capability Assumptions	Capability Areas	Potential HAT TechDev Technologies
SLS	105 t - 130 t to LEO, TBD launches/year	BEO Access	• Advanced, low Cost Engine Technology for Heavy Lift Launch Vehicle
CPS (trade)	Parametric design with each stage optimized; Zero-boil off cryo management; Stage fraction ~ 23%; Specific impulse = 465 s (LOX/LH2)	BEO Access; In-Space Propulsion; Thermal	• High Rate, Adaptive, Internetworked Proximity Communications • High Strength/Stiffness Deployable 10-100kW Arrays • In Space Cryogenic Liquid Acquisition • In-Space Cryo genic Propulsion Storage (ZBO LO2, Reduced LH2)
SM	Long-duration propellant storage; Multiple restarts; Isp = 315 s (NTO/MMH); AR&D with lunar orbit facility; provide power generation and energy storage for Orion	BEO Access; In-Space Propulsion; Robotics; Comm. & Nav.; Power and Energy Storage; Avionics	
Orion	Support 4 crew for ~21 days (during ascent and reentry); 600-1000 days dormant; Operating pressure: 10.2 to 14.7 psia; AR&D; Re-enter at Earth from Mars velocity	Habitation; ECLSS; EVA; Crew Health & Protection; Avionics; Comm. & Nav.; EDL; Radiation	• Common Avionics • High Rate, Adaptive, Internetworked Proximity Communications • Robust Ablative Heat Shield – Beyond Lunar • Space Radiation Protection and Shielding– SPE
DSH	Mass Range : 28-65 t; Support and protect crew of 4 for 600 days (short stay) or ~1000 days (long stay); Consumables loaded based on crew size & mission duration; Provide communications between mission elements and to Earth	Habitation; ECLSS; Crew Health & Protection; Destination Systems; Avionics; Logistics; Radiation; Comm. & Nav.	• Autonomous Vehicle Systems Management • Closed-Loop, High Reliability, Life Support Systems • Common Avionics • Crew Autonomy Beyond LEO • Deep Space Mission Human Factors and Habitability • Deep Space Suit • Fire Prevention, Detection, & Suppression • High Data Rate Forward Link (Flight) Communications • High Rate, Adaptive, Internetworked Proximity Comm • High Reliability Life Support Systems • In-Flight Environmental Monitoring • Long Duration Spaceflight Behavioral Health • Long Duration Spaceflight Medical Care • Mechanisms for Long Duration, Deep Space Missions • Microgravity Biomedical Counter-Measures • Microgravity Biomedical – Optimized Exercise • Mission Control Automation Beyond LEO • Quad function Hybrid RF/Optical Communication, Optical Ranging, RF Imaging System • Space Radiation Protection – GCR • Space Radiation Protection and Shielding– SPE • Suit Port • Thermal Control

Note: Capability needs still under assessment

Crewed Mars Moons Mission Potential Capabilities (2 of 2)

Element	High-level Capability Assumptions	Capability Areas	Potential HAT TechDev Technologies
SEV	Crew of 2 for 14 days; Nominal mass = 6.7 t; LOX/CH4 Stage when needed: Stage Fraction: 15%, Isp: 355 s; Enable EVA; Provide communications; Provide power; Perform science collection activities at Phobos and/or Deimos	Habitation; ECLSS; EVA; Crew Health & Protection; Destination Systems; Robotics; Avionics; Logistics; In-Space Propulsion; Autonomous Mission Operations; Comm. & Nav.; Power and Energy Storage	• AR&D and Proximity Operations • Deep Space Suit • High Data Rate Forward Link (Flight) Communications • High Rate, Adaptive, Internetworked Proximity Communications • In-Space Timing and Nav for Autonomy • Mechanisms for Long Duration, Deep Space Missions • Quad Function Comm, Optical Ranging, RF Imaging • Space Radiation Protection – GCR • Space Radiation Protection – SPE • Space Radiation Shielding – SPE • Suit Port
EVA	Advanced EVA suits and mobility for exploration	EVA	• Deep Space Suit • Suit Port
LSS / Potential Transfer Stage (trade)	TBD t storable propellant load; Long-duration propellant storage and transfer to support transfers to and from Phobos and Deimos for short-stay mission; Isp = 315 s (NTO/MMH) or 353 s (LOX/CH4); AR&D	In-Space Propulsion; Robotics	Technologies for LOX/CH4 Only: • In-Space Cryogenic Liquid Acquisition • In-Space Cryo genic Propulsion Storage (ZBO LO2, Reduced LH2) • Unsettled Cryogenic Propellant Transfer
SEP (trade)	Spacecraft alpha ~30 kg/kw, Specific impulse = 1800-6000 s Xe tank fraction = 5%, Total power varies	In-Space Propulsion	• Autonomously Deployable 300 kW In-Space Arrays • Electric Propulsion & Power Processing
NEP (trade)	Spacecraft alpha ~20 kg/kw, Specific impulse = 1800-6000 s Xe tank fraction = 5%, Total power varies	In-Space Propulsion	• 300 kWe Fission Power for Electric Propulsion • Multi-MWe Nuclear Power for Electric Propulsion
NTP (trade)	NERVA-derived common core propulsion (20 t core); 3 x 111 kN engines; Specific Impulse = 900 s; All LH2 fuel with zero boil-off; Drop tanks @ 27% tank fraction	In-Space Propulsion; Thermal; Structures, Materials, & Mechanisms	• Nuclear Thermal Propulsion (NTP) Engine
Robotics	Uncrewed operations, used for collection of samples at destination	Robotics	
	Crewed operations, used for collection of samples at destination		• Robots Working side-by-side with Suited Crew
Robotics Precursor	Independent scientific mission for mapping of Phobos and Deimos , system and technology testing, resource characterization	Robotics	

Note: Capability needs still under assessment

Crewed Mars Orbital Mission

Crewed Mars Orbit Mission

Achievements

- Crewed mission to the Martian system
- Multi-year flight of DSH
- Farthest distance that humans have traveled from Earth

Mission Operations

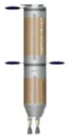
- Launch, Earth-orbit rendezvous and delivery to Martian system of pre-deployed cargo & propulsive elements
- Launch and Earth-orbit rendezvous of crewed systems & propulsive elements
- Launch of crew and rendezvous with stack and delivery to Martian System
- Teleoperation of robotic surface assets
- Total mission duration with direct entry at Earth: ~600 day (opposition-class/short-stay) to ~1000 day (conjunction-class/long-stay)

Assumed Element Capabilities

TBD t Class SLS

Orion "Block N"

Teleoperated Robots



Propulsion (O_2/CH_4 shown)

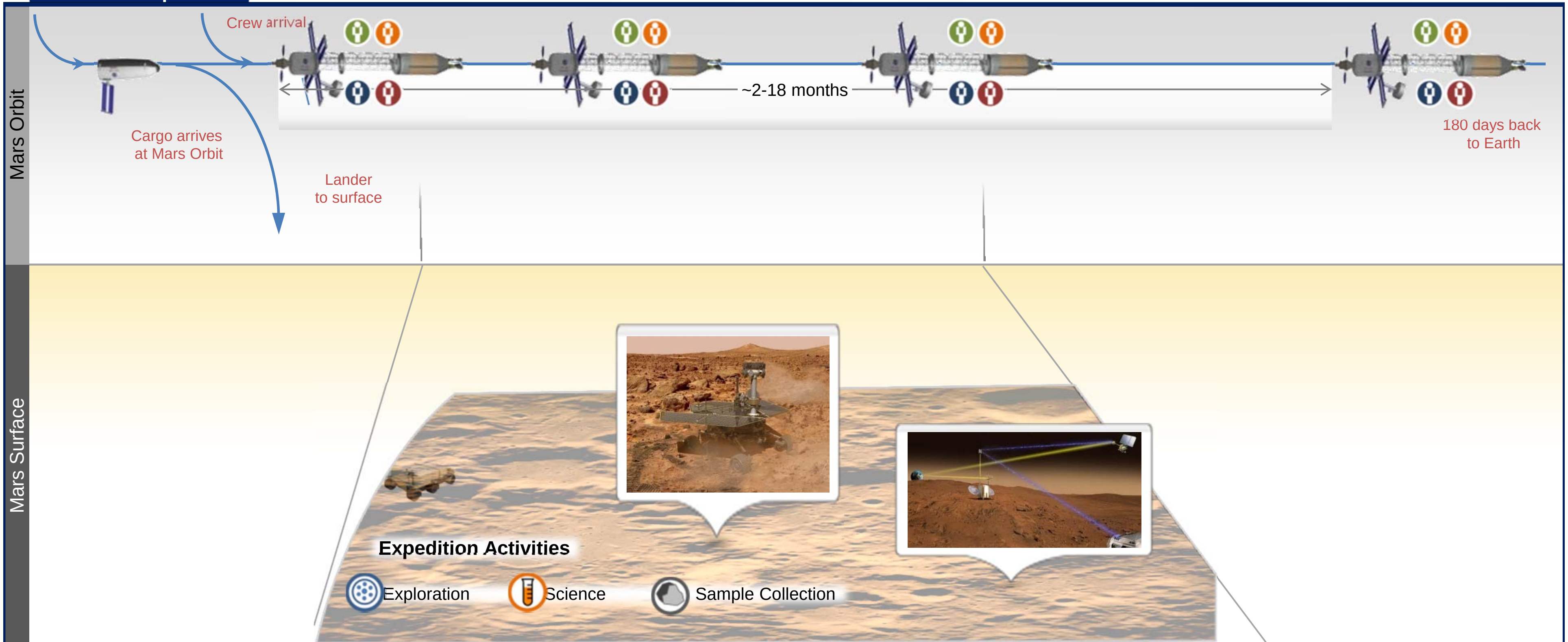
DSH

Cross-Cutting Capabilities

- Trade advanced propulsion & aerocapture
- Long-duration spaceflight healthcare and countermeasures
- Autonomous vehicle systems management
- AR&D
- ISRU surface demo
- Mechanisms for long-duration, deep-space missions

Crewed Mars Orbit Mission Notional Destination Operations

Mission Sequence



Mission Summary

- Crew orbits Mars for ~2-18 months, depending on mission class.
- Crew tele-operates surface assets while in orbit.

Mission Site: Mars Orbit

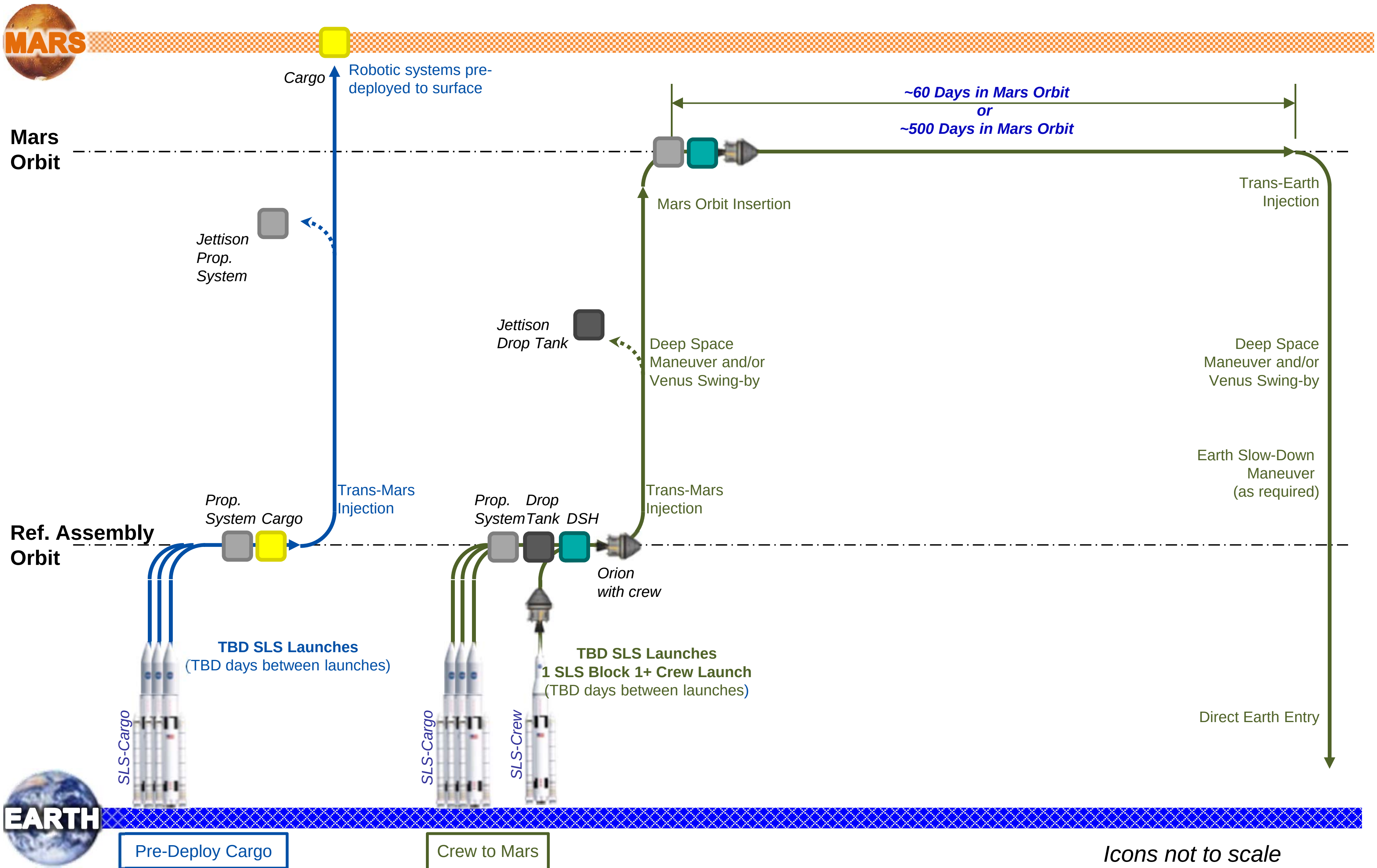
- One or more pre-emplaced tele-operated robots on Martian surface or its Moons, operating at one or more different sites
- Option for real time sample return
- In addition to science, surface robots could facilitate reconnaissance necessary for future human landing

Crewed Mars Orbit Mission Notional Destination Operations

- Crewed mission performs propulsive maneuvers for Mars orbit capture
- Stack performs orbital maneuvers to rendezvous with pre-deployed assets
- Perform Mars exploration via in-system telerobotics
  - Mars survey
  - Sample collection and analysis, science package deployment
  - Conduct technology, operations, and infrastructure demonstrations
- The stack (DSH and Orion) departs Mars orbit with crew for return to Earth
- The surface assets will continue to perform uncrewed exploration and science activities

Crewed Mars Orbit Mission Architecture

Notional Long-Stay Mars Orbit Operations



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Crewed Mars Orbit Mission Potential Capabilities (1 of 2)

Element	High-level Capability Assumptions	Capability Areas	Potential HAT TechDev Technologies
SLS	105 t - 130 t to LEO, TBD launches/year	BEO Access	• Advanced, low Cost Engine Technology for HLLV
CPS (trade)	Parametric design with each stage optimized, Zero-boil off cryo management, Stage fraction ~ 23%, Specific impulse = 465 s	BEO Access; In-Space Propulsion	• High Rate, Adaptive, Internetworked Proximity Communications • High Strength/Stiffness Deployable 10-100kW Arrays • In Space Cryogenic Liquid Acquisition
SM	Long-duration propellant storage; Multiple restarts; Isp = 315 s (NTO/MMH); AR&D with lunar orbit facility; provide power generation and energy storage for Orion	BEO Access; In-Space Propulsion; Robotics; Comm. & Nav.; Power and Energy Storage; Avionics	
Orion	Support 4 crew for ~21 days (during ascent and reentry); 600-1000 days dormant; Operating pressure: 10.2 to 14.7 psia; AR&D; Re-enter at Earth from Mars velocity	Habitation; ECLSS; EVA; Crew Health & Protection; Avionics; Comm. & Nav.; EDL; Radiation	• Common Avionics • High Rate, Adaptive, Internetworked Proximity Communications • Robust Ablative Heat Shield – Beyond Lunar • Space Radiation Protection and Shielding – SPE
DSH	Mass Range : 28-65 t; Support and protect crew of 4 for 600 days (short stay) or ~1000 days (long stay); Consumables loaded based on crew size & mission duration; Provide communications between mission elements and to Earth	Habitation; ECLSS; Crew Health & Protection; Destination Systems; Avionics; Logistics; Radiation; Comm. & Nav.	• Autonomous Vehicle Systems Management • Closed-Loop, High Reliability, Life Support Systems • Common Avionics • Crew Autonomy Beyond LEO • Deep Space Mission Human Factors and Habitability • Deep Space Suit • Fire Prevention, Detection, & Suppression • High Data Rate Forward Link (Flight) Communications • High Rate, Adaptive, Internetworked Proximity Communications • High Reliability Life Support Systems • In-Flight Environmental Monitoring • Long Duration Spaceflight Behavioral Health • Long Duration Spaceflight Medical Care • Mechanisms for Long Duration, Deep Space Missions • Microgravity Biomedical Counter-Measures • Microgravity Biomedical – Optimized Exercise • Mission Control Automation Beyond LEO • Quad function Hybrid RF/Optical Comm, Optical Ranging, RF Imaging System • Space Radiation Protection – GCR • Space Radiation Protection and Shielding– SPE • Suit Port • Thermal Control

Note: Capability needs still under assessment

Crewed Mars Orbit Mission Potential Capabilities (1 of 2)

Element	High-level Capability Assumptions	Capability Areas	Capability Needs
SEP (trade)	Spacecraft alpha ~30 kg/kw, Specific impulse = 1800-6000 s Xe tank fraction = 5%, Total power varies	In-Space Propulsion	• Autonomously Deployable 300 kW In-Space Arrays • Electric Propulsion & Power Processing
NEP (trade)	Spacecraft alpha ~20 kg/kw, Specific impulse = 1800-6000 s Xe tank fraction = 5%, Total power varies	In-Space Propulsion	• Multi-MWe Nuclear Power for Electric Propulsion
NTP (trade)	NERVA-derived common core propulsion (20 t core); 3 x 111 kN engines; Specific Impulse = 900 s; All LH2 fuel with zero boil-off; Drop tanks @ 27% tank fraction	In-Space Propulsion; Thermal; Structures, Materials, & Mechanisms	• Nuclear Thermal Propulsion (NTP) Engine
Robotics	Used for surface/Mars moons exploration while crew is in orbit	Robotics	• Robots Working side-by-side with Suited Crew

Note: Capability needs still under assessment

Crewed Mars Surface Mission (DRA 5.0)

NASA-SP-2009-566
NASA-SP-2009-566-ADD

Crewed Mars Surface Mission

DRA 5.0 Derived

Achievements

- First human landing on Mars
- Farthest distance that humans have traveled from Earth
- Extensive exploration of the surface of Mars
- First use of large scale EDL

Mission Operations

- Launch, Earth-orbit rendezvous and delivery to Martian system of pre-deployed cargo & propulsive elements
- Launch and Earth-orbit rendezvous of crewed systems & propulsive elements
- Total mission duration with direct entry at Earth ~1000 day
- Cargo elements are captured in Mars orbit using aerocapture.
- Selected surface assets pre-deployed at the landing site using advanced entry-descent-landing (EDL) technology
- Crewed vehicle utilizes propulsive capture at Mars
- 6-crew, ~540-day surface stay
- Crew lives in DSH for in-space operations, habitat lander for surface stay

Assumed Element Capabilities

TBD t Class SLS | Orion "Block N" | Habitat Lander (crewed descent) | Advanced EVA Systems | Teleoperated Robots | Advanced Propulsion (NTP shown) | Surface Systems | DSH | Aeroassist System | MAV Lander (crewed ascent)

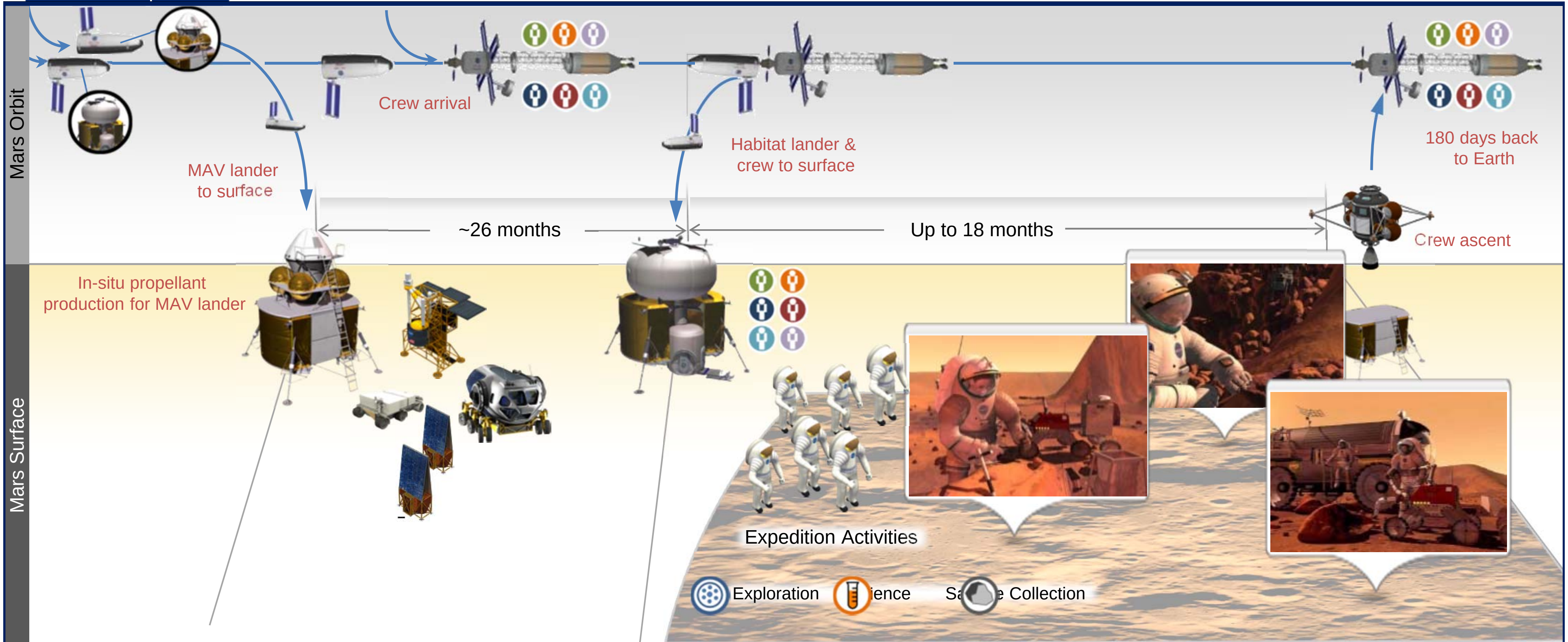
Cross-Cutting Capabilities

- Advanced propulsion & trade crew mission aerocapture
- Long-duration spaceflight healthcare and countermeasures
- Autonomous vehicle systems management
- AR&D
- ISRU
- Mechanisms for long-duration, deep-space missions

Crewed Mars Surface Mission Notional Destination Operations

DRA 5.0 Derived

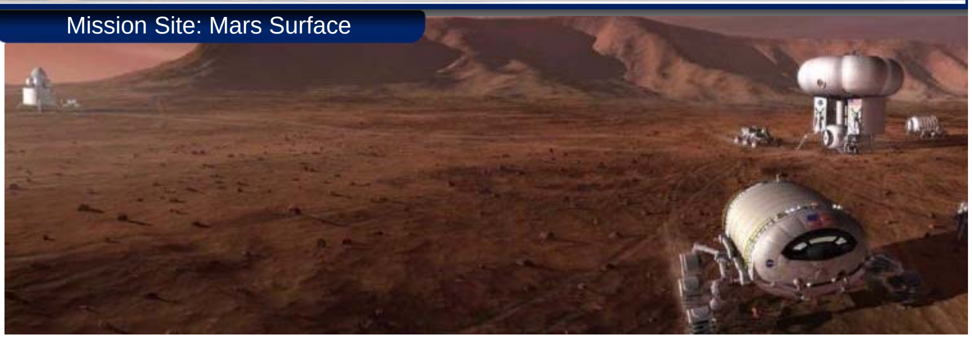
Mission Sequence



Mission Summary

- Long surface stays with visits to multiple sites provides scientific diversity
- Each mission to a different exploration site to maximize scientific return
- Mobility at great distances (100s kilometers) from the landing site enhances science return (diversity)
- Subsurface access of 100s meters or more highly desired
- Advanced laboratory and sample assessment capabilities necessary for high-grading samples for return

Mission Site: Mars Surface



Crewed Mars Surface Mission Notional Destination Operations

DRA 5.0 Derived

Cargo Pre-deploy

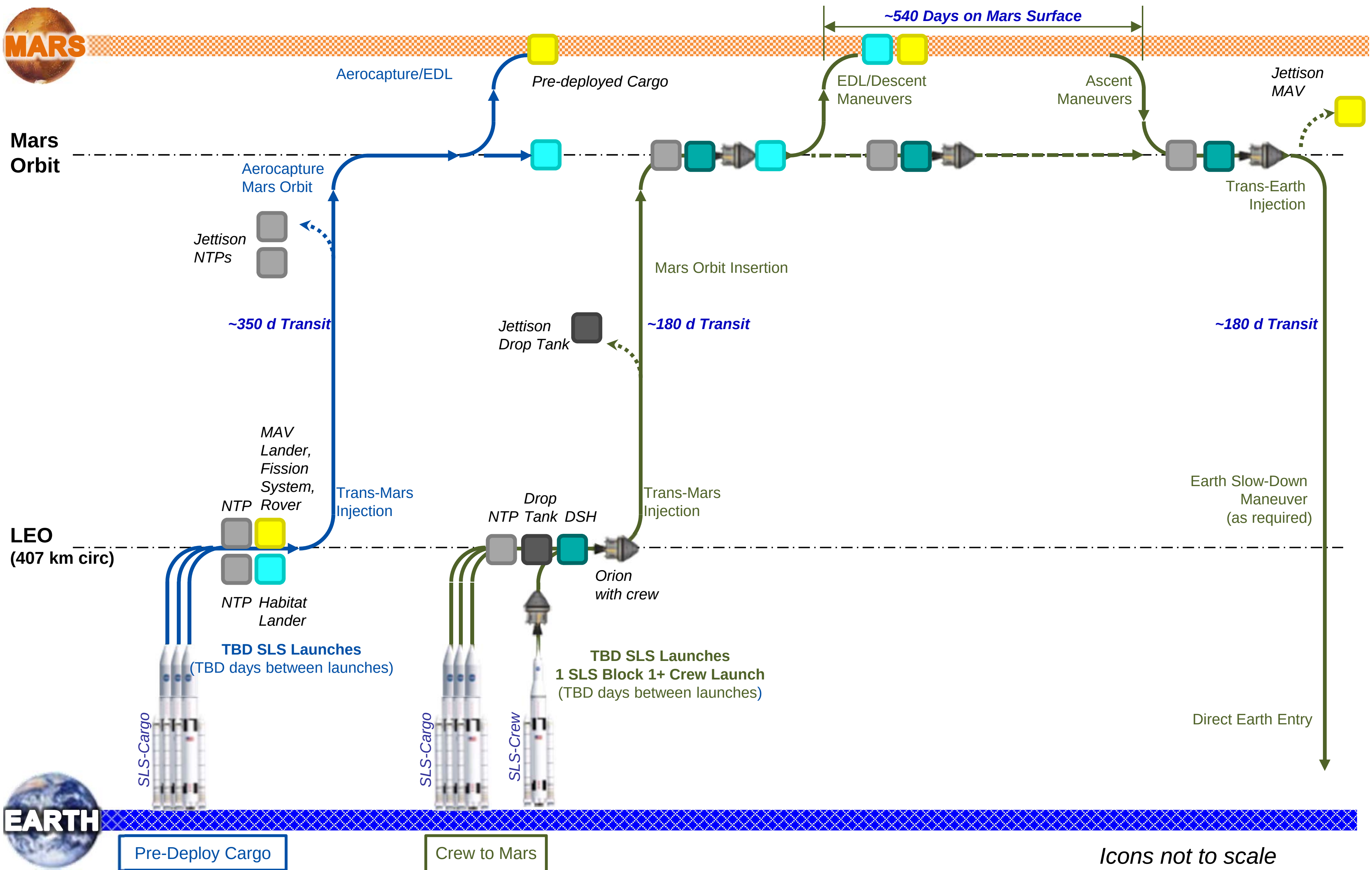
- Cargo uses aerocapture for Mars orbit insertion.
- MAV lander and surface assets depart from stack and perform descent maneuvers for pre-deploy to Mars surface
- Habitat lander remains in Mars orbit for crew
- After landing, all systems will undergo a systems check
- An Offloading Device will assist in offloading necessary surface assets
- Surface power system deployed
- Ascent oxygen produced from atmosphere and stored directly in MAV.
- Surface assets will perform verification of precursor data, final scouting of landing and explorations sites, and follow up scientific measurements if needed

Crewed Mission

- Crewed mission performs propulsive orbit capture
- Orion docks to habitat lander and crew transfer to habitat
- Habitat lander departs from stack and performs descent maneuvers to Mars surface
- Habitat provides adequate time/function for crew adaptation to Martian gravity environment
- Crew performs up to ~500 day mission living in surface assets
- During mission, the crew will perform multiple excursions from the landing site to meet science and exploration objectives
- After completion of the mission, the crew will transfer from the surface assets to the lander
- Prior to ascent, mobile surface assets will park behind the horizon or surface feature to avoid ejecta
- After crewed launch, the surface assets will continue to perform uncrewed exploration and science activities

Crewed Mars Surface Mission Architecture

DRA 5.0 Derived



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Crewed Mars Surface Mission Potential Capabilities (1 of 3)

DRA 5.0 Derived

Element	High-level Capability Assumptions	Capability Areas	Potential HAT TechDev Technologies
SLS	105 t - 130 t to LEO, TBD launches/year	BEO Access	• Advanced, low Cost Engine Technology for HLLV
CPS (trade)	Parametric design with each stage optimized, Zero-boiloff cryo management, Stage fraction ~ 23%, Specific impulse = 465 s	In-Space Propulsion; Thermal	• High Rate, Adaptive, Internetworked Proximity Communications • High Strength/Stiffness Deployable 10-100kW Arrays • In Space Cryogenic Liquid Acquisition • In-Space Cryo Prop Storage (ZBO LO2, Reduced LH2)
SM	Long-duration propellant storage; Multiple restarts; Isp = 315 s (NTO/MMH); AR&D with lunar orbit facility; provide power generation and energy storage for Orion	BEO Access; In-Space Propulsion; Robotics; Comm. & Nav.; Power and Energy Storage; Avionics	
DSH	Mass Range : 28-65 t; Support and protect crew of 6 for ~360 days (outbound and return); Consumables loaded based on crew size & mission duration; Provide communications between mission elements and to Earth	Habitation; ECLSS; Crew Health & Protection; Destination Systems; Avionics; Logistics; Radiation; Comm. & Nav.	• Autonomous Vehicle Systems Management • Closed-Loop, High Reliability, Life Support Systems • Common Avionics • Crew Autonomy Beyond LEO • Deep Space Mission Human Factors and Habitability • Deep Space Suit • Fire Prevention, Detection, & Suppression • High Data Rate Forward Link (Flight) Communications • High Rate, Adaptive, Internetworked Proximity Communications • High Reliability Life Support Systems • In-Flight Environmental Monitoring • Long Duration Spaceflight Behavioral Health • Long Duration Spaceflight Medical Care • Mechanisms for Long Duration, Deep Space Missions • Microgravity Biomedical Counter-Measures • Microgravity Biomedical – Optimized Exercise • Mission Control Automation Beyond LEO • Quad function Hybrid RF/Optical Comm, Optical Ranging, RF Imaging System • Space Radiation Protection – GCR • Space Radiation Protection and Shielding– SPE • Suit Port • Thermal Control
Orion	Support 6 crew for TBD days (during ascent and reentry); 500 days dormant; Operating pressure: 10.2 to 14.7 psia; AR&D; Re-enter at Earth from Mars velocity	Habitation; ECLSS; EVA; Crew Health & Protection; Avionics; Comm. & Nav.; EDL; Radiation	• Common Avionics • High Rate, Adaptive, Internetworked Proximity Communications • Robust Ablative Heat Shield (beyond Lunar return conditions) Thermal Protection Systems • Space Radiation Protection and Shielding – SPE • Mission Control Automation Beyond LEO • Entry, Descent and Landing (EDL) Technologies – Earth Return

Note: Capability needs still under assessment

Crewed Mars Surface Mission Potential Capabilities (2 of 3)

DRA 5.0 Derived

Element	High-level Capability Assumptions	Capability Areas	Potential HAT TechDev Technologies
Mars Descent Module	Perform terminal Mars descent, Precision landing, cargo and crewed versions, Propellant storage and transfer	In-Space Propulsion; Destination Systems; Robotics; Avionics	• Common Avionics • High Rate, Adaptive, Internetworked Proximity Communications • In Space Cryogenic Liquid Acquisition • LOX/Liquid Methane Cryogenic Propulsion System • LOX/Liquid Methane Reaction Control Engines • Precision Landing & Hazard Avoidance • Unsettled Cryogenic Propellant Transfer
Mars Ascent Vehicle	Habitation (6 crew, < 2 days), egress/ingress, Perform Mars ascent, R&D with return stack, Propellant storage and transfer	In-Space Propulsion; Habitation; ECLSS; EVA; Crew Health & Protection; Robotics; Avionics; Logistics; Destination Systems	• Common Avionics • Dust Mitigation • Fire Prevention, Detection, & Suppression • High Rate, Adaptive, Internetworked Prox. Comm. • In Space Cryogenic Liquid Acquisition • LOX/Liquid Methane Cryo Prop System • LOX/Liquid Methane Reaction Control Engines • Unsettled Cryogenic Propellant Transfer • Deep Space Mission Human Factors and Habitability
EVA	Advanced EVA suits and mobility for exploration	EVA; Robotics	• Mars Space Suit (Block 3) • Suit Port
NEP (trade)	Spacecraft alpha ~20 kg/kw; Specific impulse = 1800-6000 s; Xe tank fraction = 5%; Total power varies	In-Space Propulsion; Power and Energy Storage	• 300 kWe Fission Power for Electric Propulsion • Multi-MWe Nuclear Power for Electric Propulsion
NTP (trade)	NERVA-derived common core propulsion (20 t core); 3 x 111 kN engines; Specific Impulse = 900 s; All LH2 fuel with zero boil-off; Drop tanks @ 27% tank fraction	In-Space Propulsion; Power and Energy Storage; Thermal	• Nuclear Thermal Propulsion (NTP) Engine
Robotics	Uncrewed operations, used for collection of samples at destination	Robotics; Autonomous Mission Operations	
	Crewed operations, used for collection of samples at destination		• Robots Working side-by-side with Suited Crew

Note: Capability needs still under assessment

Crewed Mars Surface Mission Potential Capabilities (3 of 3)

DRA 5.0 Derived

Element	High-level Capability Assumptions	Capability Areas	Potential HAT TechDev Technologies
Surface Systems	Support 6 crew for ~500 days on surface; Operating pressure: 8 to 10.2 psia; Surface EVA capability; Crewed and uncrewed operations; Provide surface power; SPE protection and dust mitigation; Surface mobility; Provide communications	Habitation; ECLSS; EVA; Crew Health & Protection; Destination Systems; Robotics; Comm. & Nav.; Logistics; Robotics; Autonomous Mission Operations; Power and Energy Storage	• Autonomous Vehicle Systems Management • Deep Space Mission Human Factors & Habitability • Dust Mitigation • Fire Prevention, Detection, & Suppression • High Rate, Adaptive, Internetworked Proximity Communications • High Reliability Life Support Systems • In-Flight Environmental Monitoring • Lightweight and Efficient Structures and Materials • Long Life Batteries • Low Temperature Mechanisms • Robots Working side-by-side with Suited Crew • Space Radiation Protection and Shielding – SPE • Suit Port • Surface Mobility • Thermal Control • Fission Power for Surface Missions • Regenerative Fuel Cells • High Specific Energy Batteries • Quad Function Hybrid RF/Optic Comm, Optical Ranging, RF Imaging Systems • Mars Surface Space Suit (Block 3) • Mars ISRU: Oxygen from Atmosphere & Water Extraction from Soil • Deep Space Mission Human Factors & Habitability • Mechanisms for Long Duration, Deep Space Missions • Inflatable: Structures and Materials for Inflatable Modules
Aeroassist System	Mars decelerator approaches; operational under low-g(0.1g) propulsion accelerations; for transition from supersonic flight to powered descent at Mars, and for earth re-entry vehicle	EDL; Structures, Materials, and Mechanisms; In-Space Propulsion; Thermal	• Entry, Descent and Landing (EDL) Technologies – Mars Exploration Class Missions

Note: Capability needs still under assessment

Crewed Mars Surface Mission (Minimal)

Crewed Mars Surface Mission

Minimal Mars Surface Mission

Achievements

- First human landing on Mars
- Farthest distance that humans have traveled from Earth
- Minimal human exploration of the surface of Mars (days)
- First use of large scale EDL

Mission Operations

- Launch and Earth-orbit rendezvous of crewed systems & propulsive elements
- Total mission duration with direct entry at Earth ~1000 day
- Cargo elements are captured in Mars orbit using aerocapture
- Crewed vehicle utilizes propulsive capture at Mars
- 3-crew to Mars orbit, 2-crew for 7-day surface stay
- Crew lives in DSH for in-space operations, lander for surface stay

Assumed Element Capabilities

TBD t Class SLS | Orion "Block N" | Advanced EVA Systems | DSH | Aeroassist System | Propulsion (O_2/CH_4 shown) | MAV Lander | Teleoperated Robots | Unpressurized Rover

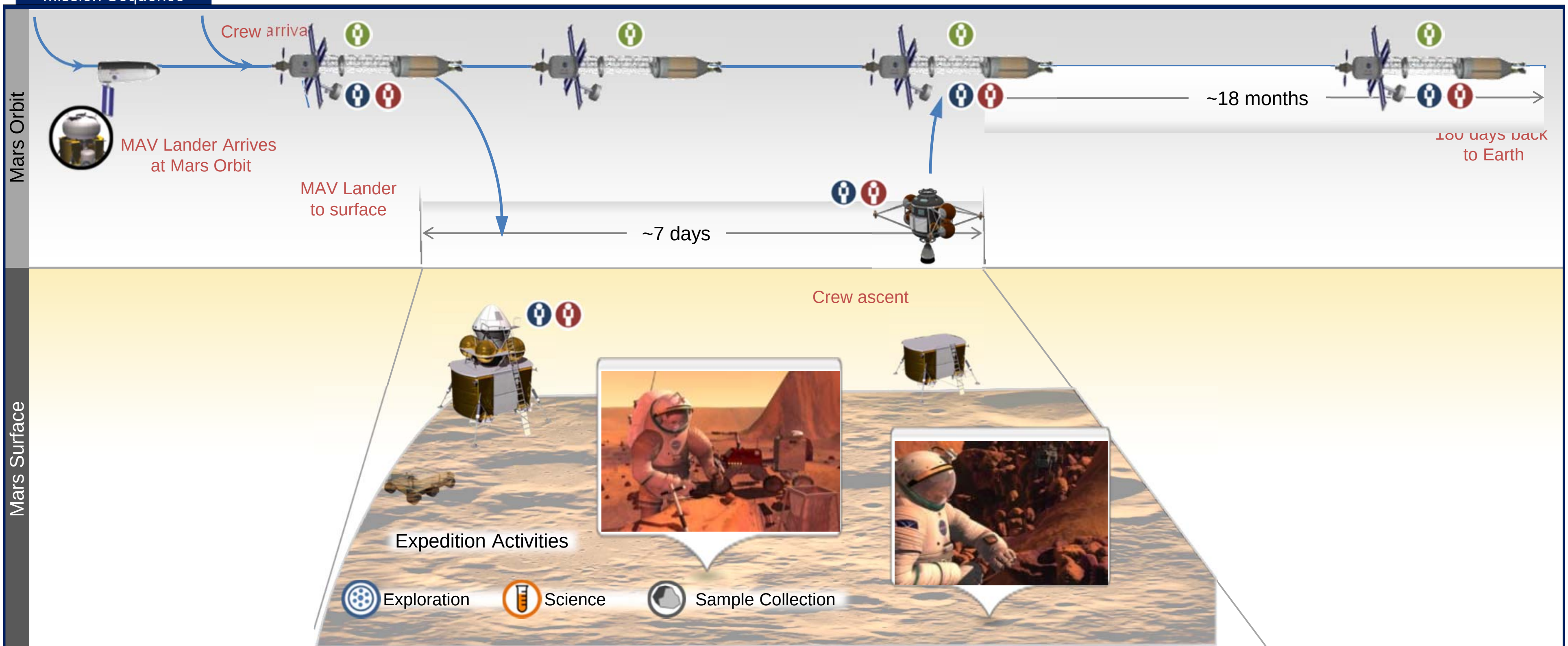
Cross-Cutting Capabilities

- Trade advanced propulsion & crew mission aerocapture
- Long-duration spaceflight healthcare and countermeasures
- Autonomous vehicle systems management
- AR&D
- ISRU demonstration on surface
- Mechanisms for long-duration, deep-space missions

Crewed Mars Surface Mission Notional Destination Operations

Minimal Mars Surface Mission

Mission Sequence



Mission Summary

- Short surface stay provides scientific diversity
- Sustainability objectives favor return missions to a single site (objectives lend themselves best to repeated visits to a specific site on Mars)
- Collect 100 kg of samples for return

Mission Site: Mars Surface

- Similar in scope to Apollo Lunar exploration capability
  - Exploration radius limited by mobility options
  - EVA a function of astronaut ability to adapt rapidly to partial g environment

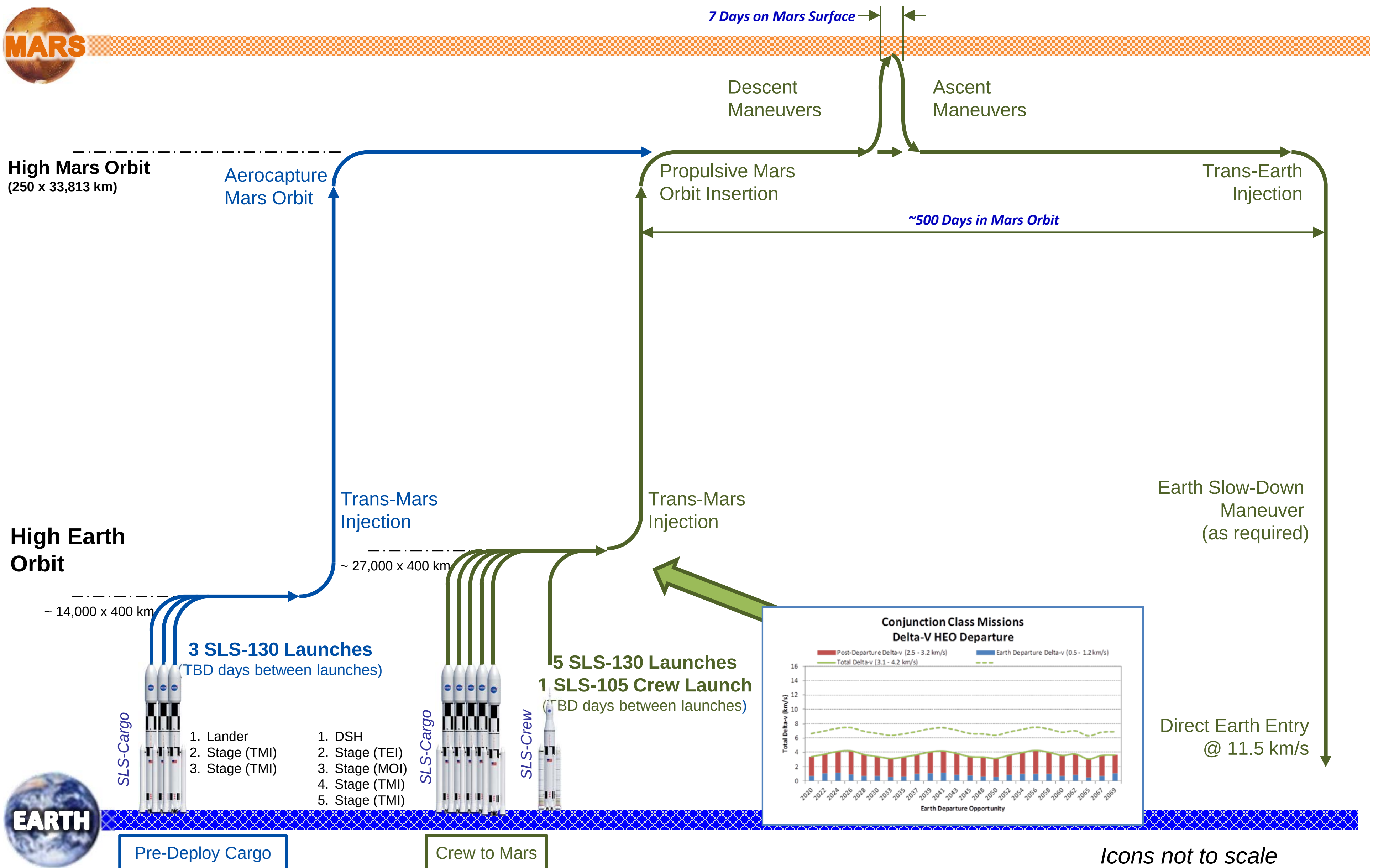
Crewed Mars Surface Mission Notional Destination Operations

Minimal Mars Surface Mission

- Crewed mission performs propulsive maneuvers for Mars orbit
- Mars lander departs from stack and performs descent maneuvers to Mars surface
- After landing, all systems will undergo a systems check
- An offloading device will assist in offloading necessary surface assets
- Crew performs up to 7 day mission living in surface assets
- During mission, the crew will perform multiple excursions from the landing site to meet science and exploration objectives
- After completion of the mission, the crew will transfer from the surface assets to the lander
- Prior to ascent, mobile surface assets will park behind the horizon or surface feature to avoid ejecta
- After crewed launch, the surface assets will continue to perform uncrewed exploration and science activities

Crewed Mars Surface Mission Architecture

Minimal Mars Surface Mission



Icons not to scale

Crewed Mars Surface Mission Potential Capabilities (1 of 2)

Minimal Mars Surface Mission

Element	High-level Capability Assumptions	Capability Areas	Potential HAT TechDev Technologies
SLS	105 t - 130 t to LEO; TBD launches/year	BEO Access	• Advanced, low Cost Engine Technology for HLLV
CPS	Parametric design with each stage optimized; Zero-boil off cryo management; Stage fraction ~ 23%; Specific impulse = 465 s	BEO Access; In-Space Propulsion; Thermal	• High Rate, Adaptive, Internetworked Proximity Communications • High Strength/Stiffness Deployable 10-100kW Arrays • In Space Cryogenic Liquid Acquisition
SM	Long-duration propellant storage; Multiple restarts; Isp = 315 s (NTO/MMH); AR&D with lunar orbit facility; provide power generation and energy storage for Orion	BEO Access; In-Space Propulsion; Robotics; Comm. & Nav.; Power and Energy Storage; Avionics	
Orion	Support 3 crew for TBD days (during ascent and reentry); Operating pressure: 10.2 to 14.7 psia; AR&D; Re-enter at Earth from Mars velocity	Habitation; ECLSS; EVA; Crew Health & Protection; Avionics; Comm. & Nav.; EDL; Radiation	• Common Avionics • High Rate, Adaptive, Internetworked Proximity Communications • Robust Ablative Heat Shield – Beyond Lunar • Space Radiation Protection & Shielding – SPE • Mission Control Automation Beyond LEO • Entry, Descent and Landing (EDL) Technologies – Earth Return
DSH	Mass Range: 28-65 t; Support and protect crew of 3 for ~1000 days (outbound, stay time, and return); Consumables loaded based on crew size & mission duration; Provide communications between mission elements and to Earth	Habitation; ECLSS; Crew Health & Protection; Destination Systems; Avionics; Logistics; Radiation; Comm. & Nav.	• Autonomous Vehicle Systems Management • Closed-Loop, High Reliability, Life Support Systems • Common Avionics • Crew Autonomy Beyond LEO • Deep Space Mission Human Factors and Habitability • Deep Space Suit • Fire Prevention, Detection, & Suppression • High Data Rate Forward Link (Flight) Communications • High Rate, Adaptive, Internetworked Proximity Communications • High Reliability Life Support Systems • In-Flight Environmental Monitoring • Long Duration Spaceflight Behavioral Health • Long Duration Spaceflight Medical Care • Mechanisms for Long Duration, Deep Space Missions • Microgravity Biomedical Counter-Measures • Microgravity Biomedical – Optimized Exercise • Mission Control Automation Beyond LEO • Quad function Hybrid RF/Optical Comm, Optical Ranging, RF Imaging System • Space Radiation Protection – GCR • Space Radiation Protection & Shielding – SPE • Suit Port • Thermal Control

Note: Capability needs still under assessment

Crewed Mars Surface Mission Potential Capabilities (2 of 2)

Minimal Mars Surface Mission

Element	High-level Capability Assumptions	Capability Areas	Potential HAT TechDev Technologies
Mars Descent Module	Perform terminal Mars descent, Precision landing, Deliver crew and cargo on same descent, Propellant storage and transfer	In-Space Propulsion; Destination Systems; Robotics; Avionics	• Common Avionics • High Rate, Adaptive, Internetworked Proximity Communications • In Space Cryogenic Liquid Acquisition • LOX/Liquid Methane Cryo Prop System • LOX/Liquid Methane Reaction Control Engines • Precision Landing & Hazard Avoidance
Mars Ascent Vehicle	Habitation (2 crew, 7 days), egress/ingress, Perform Mars ascent, R&D with return stack, Propellant storage and transfer	In-Space Propulsion; Habitation; ECLSS; EVA; Crew Health & Protection; Robotics; Avionics; Logistics; Destination Systems	• Common Avionics • Dust Mitigation • Fire Prevention, Detection, & Suppression • High Rate, Adaptive, Internetworked Proximity Communications • In Space Cryogenic Liquid Acquisition • LOX/Liquid Methane Cryo Prop System • LOX/Liquid Methane Reaction Control Engines
Robotics	Uncrewed operations, used for collection of samples at destination	Robotics; Autonomous Mission Operations	
	Crewed operations, used for collection of samples at destination		• Robots Working side-by-side with Suited Crew
EVA	Advanced EVA suits and mobility for exploration	EVA; Robotics	• Mars Space Suit (Block 3) • Suit Port
Aeroassist System	Mars decelerator approaches, operational under low-g(0.1g) propulsion accelerations, for transition from supersonic flight to powered descent at Mars, and for earth re-entry vehicle	EDL; Structures, Materials, and Mechanisms; In-Space Propulsion; Thermal	• Entry, Descent and Landing (EDL) Technologies – Mars Exploration Class Missions

Note: Capability needs still under assessment

NASA Support of Internationally Led Design Reference Missions

DRM Title	Destination	Mission Class
Mission Under Development		
EM-1:Exploration Mission 1 *(not currently in package)*	Translunar	Extending Reach Beyond LEO
EM-2: Exploration Mission 2 *(not currently in package)*	Translunar	Extending Reach Beyond LEO
EM-X: Exploration Mission X *(not currently in package)*	Translunar	Extending Reach Beyond LEO
Primary DRMS		
DRM - 5: Crewed Visit to a Redirected Asteroid	Lunar DRO	Into the Solar System
DRM - 8: Crewed Mars Moons Mission	Mars Moons	Exploring Other Worlds
DRM - 8a: Crewed Mars Orbital Mission	Mars Orbit	Planetary Exploration
DRM - 9: Crewed Mars Surface Mission (DRA 5.0)	Mars Surface	Planetary Exploration
DRM - 9a: Crewed Mars Surface Mission (Minimal)	Mars Surface	Planetary Exploration
NASA Support of Internationally Led Design Reference Mission		
DRM - 7: Crew to Lunar Surface (ISECG GER)	Moon	Exploring Other Worlds
Secondary DRMs		
Translunar Missions *(not currently in package)*	Translunar	Extending Reach Beyond LEO
DRM - 6: 3-Launch SLS-Class Crewed NEA Mission *(not currently in package)*	NEA	Exploring Other Worlds
DRM - 7a: Crew to Lunar Surface (Minimal) *(not currently in package)*	Moon	Exploring Other Worlds
DRM - 7b: Mars Test on Moon *(not currently in package)*	Moon	Exploring Other Worlds

DRM – 7: Crew to Lunar Surface (ISECG GER)

Note: NASA involvement assumes other International partners lead the effort along with the requisite contribution of resources and hardware from those partners (e.g. dissimilar crew transportation, landers, cargo, surface elements, in-space elements, etc.).

Crew to Lunar Surface (ISECG GER)

Achievements

- Return human presence to the Moon
- Repeated crewed access to lunar polar regions

Mission Operations

- Crew access Lunar surface with a RLM utilizing an in-space facility in lunar vicinity
- ICPS + Large Storable Stage (LSS) performs TLI and LOI
- A disposable braking stage (LSS or SM) will perform up to 90% of the descent burn
- Surface systems will be pre-deployed on separate cargo missions
- 4-crew (will strive for 4, but most likely 2 in orbit, 2 to surface due to transportation constraints), build to 28-day surface stays, 5 crewed missions over 5 years
- Crew lives in mobile assets (RLM is a taxi)
- 2 x Evolved (Block 1+) SLSs (>105t to LEO, >25t to lunar orbit insertion) required per crewed mission

Assumed Element Capabilities

Block 1+ SLS

ICPS or CPS

Orion “Block 0 Lunar”

Braking Stage/LSS

Reusable LM

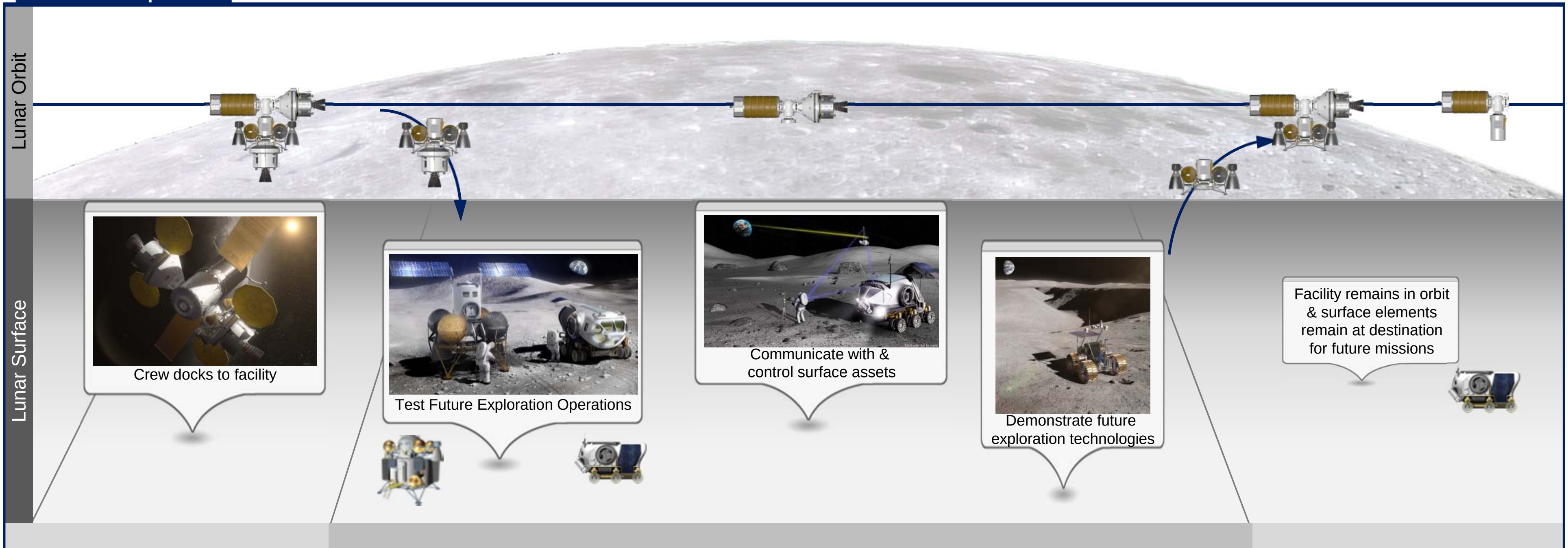
Surface Systems

Cross-Cutting Capabilities

- AR&D (Assumed for Facility docking)
- Automated Landing/Hazard Avoidance
- Communications (surface and in-space)
- Avionics
- Propellant Transfer (NTO/MMH or LOx/CH_4)
- Propellant Storage (~1 year for LOx/CH_4 LM only)
- Power generation and energy storage (surface and in-space)
- Advanced EVA (surface and contingency in-space)

Crew to Lunar Surface (ISECG GER) Notional Destination Operations

Mission Sequence



Mission Summary

Mission Benefits

- Reduces risk for future human and robotic exploration missions
- Enhances lunar and space science
- Develops capabilities required for future Mars missions

Crew to Lunar Surface (ISECG GER) Destination Operations

Cargo Pre-deploy

- After landing, all systems will undergo a systems check
- An offloading device will assist in offloading all surface assets (all assets are mobile or connected to a mobile asset)
- Surface assets will perform verification of precursor data, final scouting of landing and explorations sites, and follow up scientific measurements if needed
- Prior to crewed landing, surface assets will park behind horizon or surface feature to avoid ejecta

Crewed Mission

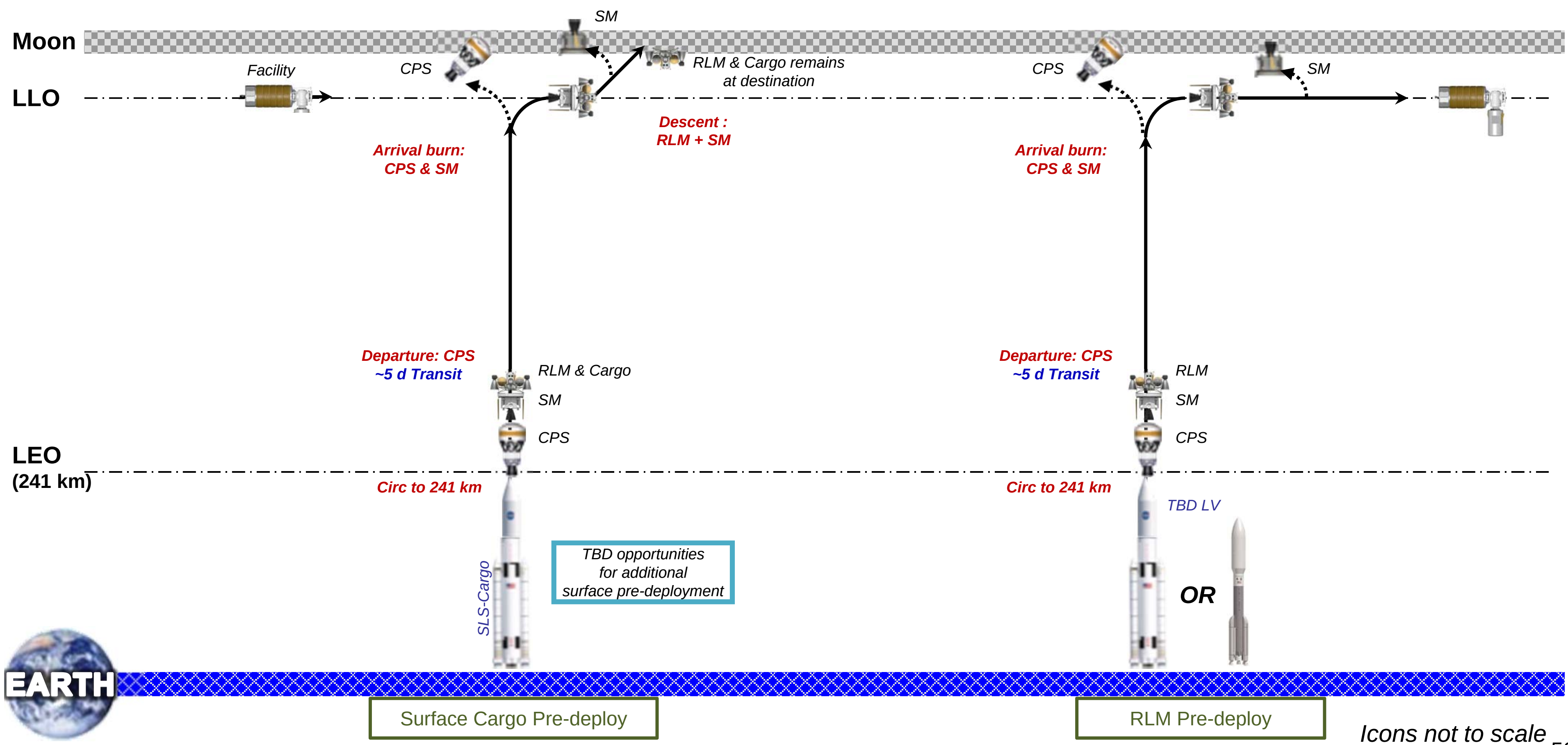
- Within hours of crewed landing, the surface assets approach the lander
- Crew transfer from lander cabin to surface assets (method TBD)
- Crew performs up to 28 day mission living in surface assets
- During mission, the crew will perform TBD excursions from the landing site to meet science and exploration objectives
- After completion of the mission, the crew will transfer from the surface assets to the lander (method TBD)
- Prior to ascent, surface assets will park behind the horizon or surface feature to avoid ejecta
- After crewed launch, the surface assets will continue perform uncrewed exploration and science activities
- Surface assets traverse to next crewed landing site

Crew to Lunar Surface (ISECG GER) Mission Architecture – Pre-deploy to Lunar Orbit

One-Way Cargo Pre-deploy Mission and LM Pre-deploy Mission

Transportation:
- Lunar Surface
- Block 1+ SLS
- CPS
- SM

Destination:
- Time at Destination: TBD d
- Cargo Mass: TBD kg
  - Type: TBD
- Resources/Trash left: TBD kg
  - Type: TBD
- Samples/Cargo returned to Earth: n/a kg
  - Type: n/a



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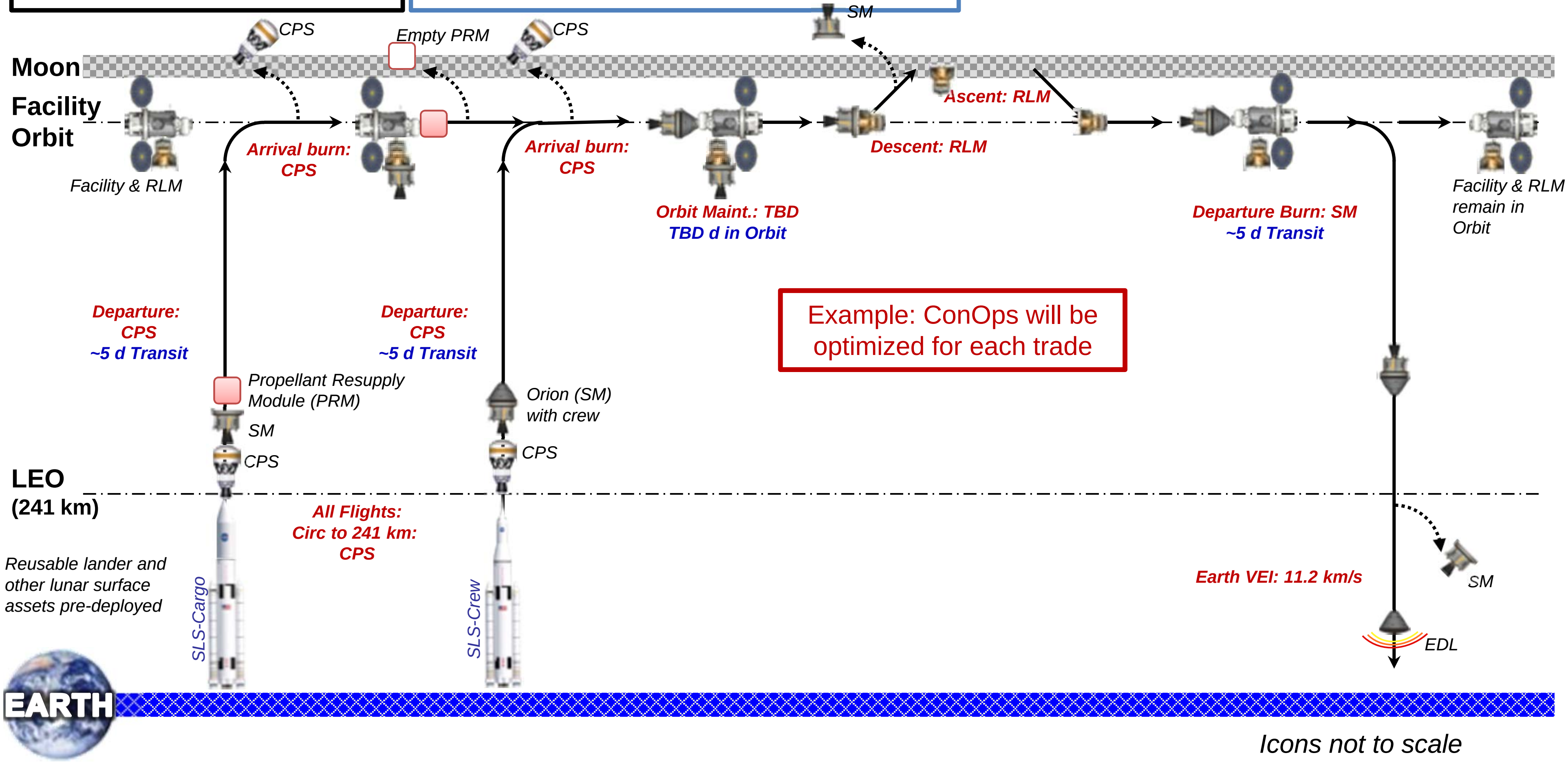
Crew to Lunar Surface (ISECG GER) Mission Architecture – Crew to Lunar Surface

Two-Launch Crewed Mission (Recurring)

Transportation:
- Lunar Surface
- Crewed mission duration ~28 d on surface
- 4 crew members
- Block 1+ SLS
- CPS
- SM

Destination:
- Time at Destination: ~28 d
- Cargo Mass: 500 kg (TBR)
  - Type: TBD
- Resources left: TBD kg
  - Type: TBD
- Samples/Cargo returned to Earth: 250 kg (TBR)
  - Type: TBD



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Crew to Lunar Surface (ISECG GER) Potential Capabilities (1 of 2)

Element	High-level Capability Assumptions	Capability Areas	Potential HAT TechDev Technologies
Block 1+ SLS	Block 1+ to LEO; 2 launches per mission	BEO Access	• Advanced, low Cost Engine Technology for HLLV
ICPS (trade option)	TLI capability; short duration stage; Isp = 465 s	BEO Access; In-Space Propulsion	
CPS	TLI and LOI capability; 5-day lifetime with multiple restarts; Isp = 465 s; AR&D with lunar orbit facility	BEO Access; In-Space Propulsion; Avionics	• In Space Cryogenic Liquid Acquisition
SM	Long-duration propellant storage; Multiple restarts; Isp = 315 s (NTO/MMH); AR&D with lunar orbit facility; provide power generation and energy storage for Orion	BEO Access; In-Space Propulsion; Robotics; Comm. & Nav.; Power and Energy Storage; Avionics	
LSS (trade option)	10 - 48t storable propellant load; Long-duration propellant storage; Isp = 315 s (NTO/MMH) or 353 s (LOX/CH4); AR&D with lunar orbit facility	In-Space Propulsion; Robotics; Comm. & Nav.; Avionics	• LOX/Liquid Methane Cryogenic Propulsion System • LOX/Liquid Methane Reaction Control Engines
Orion	Support 4 crew for ~10 days (transit to/from Moon); Operating pressure: 10.2 to 14.7 psia; rendezvous and dock with lunar orbit facility; Re-enter at Earth from lunar velocity	Habitation; ECLSS; EVA; Crew Health & Protection; Avionics; Comm. & Nav.; EDL; Radiation	• Common Avionics • High Rate, Adaptive, Internetworked Proximity Communications • Robust Ablative Heat Shield – Thermal Protection Sys • Space Radiation Protection and Shielding – SPE
Reusable LM	Provide habitation (4 crew, < 3 days) during descent and ascent; Operating pressure: 8 to 10.2 psia; IVA or EVA egress/ingress; Perform terminal lunar descent and ascent; Survive for 5 missions in 5 yrs.; ~10s of restarts; Precision landing; AR&D with lunar facility; Propellant storage and transfer; Batteries for ascent/descent with solar arrays to recharge during surface stay	Habitation; ECLSS; EVA; Crew Health & Protection; In-Space Propulsion; Destination Systems; Robotics; Avionics; Power and Energy Storage; Radiation	• AR&D and Proximity Operations • Common Avionics • Dust Mitigation • Fire Prevention, Detection, & Suppression • High Rate, Adaptive, Internetworked Proximity Communications • In Space Cryogenic Liquid Acquisition • LOX/Liquid Methane Cryogenic Propulsion System • LOX/Liquid Methane Reaction Control Engines • Precision Landing & Hazard Avoidance
Lunar Vicinity Facility	Habitation (4 crew, TBD days); Operating pressure: 10.2-14.7 psia (trade); IVA and EVA egress/ingress; 10 year lifetime; Allow for AR&D and docking; Provide logistics for surface missions; Provide power while crew are docked and between missions	Habitation; ECLSS; EVA; Crew Health & Protection; Robotics; Avionics; Logistics; Power and Energy Storage; Radiation	• AR&D and Proximity Operations • Common Avionics • Fire Prevention, Detection, & Suppression • High Rate, Adaptive, Internetworked Proximity Communications

Note: Capability needs still under assessment

Crew to Lunar Surface (ISECG GER) Potential Capabilities (2 of 2)

Element	High-level Capability Assumptions	Capability Areas	Potential HAT TechDev Technologies
Surface Systems	Support 4 crew for 28 days on surface; Operating pressure: 8 to 10.2 psia; Surface EVA capability; Crewed and uncrewed operations; 5 missions in 5 yrs; Provide surface power (PUP); SPE protection and dust mitigation; Provide surface mobility (rovers); Provide communications between surface elements and with Earth	Habitation; ECLSS; EVA; Crew Health & Protection; Destination Systems; Robotics; Mobility Systems; Comm. & Nav.; Logistics; Autonomous Mission Operations; Radiation	• Autonomous Vehicle Systems Management • Deep Space Mission Human Factors & Habitability • Dust Mitigation • Fire Prevention, Detection, & Suppression • High Rate, Adaptive, Internetworked Prox. Comm. • High Reliability Life Support Systems • In-Flight Environmental Monitoring • Lightweight and Efficient Structures and Materials • Long Life Batteries • Low Temperature Mechanisms • Lunar ISRU: Oxygen/Water Extraction • Lunar Surface Space Suit (Block 2) • Robots Working side-by-side with Suited Crew • Space Radiation Protection and Shielding – SPE • Suit Port • Surface Mobility • Thermal Control

Note: Capability needs still under assessment

BACKUP

Acronyms

- A/L: Airlock
- ACES: Advanced Crew Escape Suit
- ACS: Attitude Control System
- AES: Advanced Exploration Systems
- ALC: Airlock-derived Logistics Carrier
- AM: Ascent Module
- AR&D: Autonomous Rendezvous and Docking
- ARM: Asteroid Retrieval Mission
- ARV: Asteroid Redirect Vehicle
- ATP: Authority to Proceed

- BEO: Beyond Earth Orbit

- C3: Square of the Hyperbolic Excess Velocity
- CEV: Crew Exploration Vehicle
- CM: Crew Module
- CLS: Cis-Lunar Spacecraft
- ConOps: Concept of Operations
- CPS: Chemical Propulsion System

- DAV: Descent/Ascent Vehicle
- DM: Descent Module
- DRA: Design Reference Architecture
- DRM: Design Reference Mission
- DRO: Distance Retrograde Orbit
- DSH: Deep Space Habitat
- DSM: Deep Space Maneuver

- ECLSS: Environmental Control and Life Support System
- EDL: Entry, Descent, Landing
- E-M L1 (L1): Earth-Moon Lagrange point 1
- E-M L2 (L2): Earth-Moon Lagrange point 2
- EM-1: Exploration Mission 1
- EM-2: Exploration Mission 2
- EMU: Extravehicular Mobility Unit
- EVA: Extra-Vehicular Activity

- FPR: Flight Performance Reserve
- FSP: Fission Surface Power
- FY: Fiscal Year

- GCR: Galactic Cosmic Rays
- GEO: Geostationary Earth Orbit
- GER: Global Exploration Roadmap

- HAID: Hypersonic Inflatable Aerodynamic Decelerator
- HAT: Human Spaceflight Architecture Team
- HEFT: Human Exploration Framework Team
- HELO: High Elliptical Lunar Orbit (100 x 10,000 km)
- HEO: High Earth Orbit
- HLLV: Heavy Lift Launch Vehicle
- HLR: Human Lunar Return
- HMO: High Mars Orbit
- HRP: Human Research Program

- ICPS: Interim Chemical Propulsion System
- ISECG: International Space Exploration Coordination Group
- ISRU: In-Situ Resource Utilization
- ISS: International Space Station
- IVA: Intra-Vehicular Activities

- JSC: Johnson Space Center

- LCM: Lunar Crew Module
- LDRO: lunar distant retrograde orbit
- LEO: Low Earth Orbit
- LLO: Low Lunar Orbit (100 km circular)
- LM: Lander Module
- LOI: Lunar Orbit Insertion
- LPM: Lunar Propulsion Module
- LPMA: Lunar Propulsion Module Ascent
- LPMD: Lunar Propulsion Module Descent
- LSM: Lunar Service Module
- LSS: Large Storable Stage
- LV: Launch Vehicle

- MACES: Modified Advanced Crew Escape Suit
- MAS: Mars Ascent Stage
- MAV: Mars Ascent Vehicle
- MCC: Mid-Course Correction
- MDS: Mars Descent Stage
- MEPAG: Mars Exploration Program Analysis Group
- MGA: Mass Growth Allocation
- MFR: Mission Formulation Review
- MLO: Medium Lunar Orbit (1,000 km circular)
- MOEV: Mars Orbital Excursion Vehicle
- MOI: Mars Orbit Insertion
- MR: Mass Ratio
- MSH: Mars Surface Habitat
- MSR: Mars Sample Return
- MTH: Mars Transit Habitat
- MTV: Mars Transfer Vehicle

- NBL: Neutral Buoyancy Laboratory
- NEA: Near-Earth Asteroid
- NEP: Nuclear Electric Propulsion
- NTP: Nuclear Thermal Propulsion
- NTR: Nuclear Thermal Rocket

- OMS: Orbital Maneuvering System

- PCT: Portable Communications Terminal
- PHA: Potentially Hazardous Asteroid
- PLSS: Portable Life Support System
- PNT: Position determination, Navigation, and Timing
- PPBE: Planning Programming Budgeting and Execution
- PRM: Propellant Resupply Module
- PUP: Portable Utility Pallet

- RCS: Reaction Control System
- REM: Robotics EVA Module
- RF: Radio Frequency
- RFC: Reusable Fuel Cells
- RFI: Request For Information
- RLM: Reusable Lander Module
- RPOD: Rendezvous Proximity Operations & Docking
- SA: Spacecraft Adapter
- SBAG: Small Bodies Assessment Group
- SEP: Solar Electric Propulsion
- SEV: Space Exploration Vehicle
- SHAB: Surface Habitat
- SKG: Strategic Knowledge Gap
- SLS: Space Launch System
- SM: Service Module
- SPE: Solar Particle Event
- SPR: Small Pressurized Rovers
- STEM: Science, Technology, Engineering, and Mathematics
- STMD: Space Technology Mission Directorate

- TBD: To Be Determined
- TBR: To Be Reviewed
- TCM: Trajectory Correction Maneuver
- TEI: Trans-Earth Injection
- TLI: Trans-Lunar Injection
- TMI: Trans-Mars Injection
- TOF: Time of Flight

- VEI: Velocity at Entry Interface

- ZBO: Zero-Boil Off

- ΔV: change in velocity